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Information and Communication Technologies for Ageing Well and e-Health

Third International Conference, ICT4AWE 2017
Porto, Portugal, April 28–29, 2017
Revised Selected Papers

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Preface

We are delighted to present the extended and revised versions of a set of selected papers from the Third International Conference on Information and Communication Technologies for Ageing Well and e-Health (ICT4AWE 2017), held in Porto, Portugal, during April 28–29, 2017.

ICT4AWE 2017 received 32 paper submissions from 19 countries, of which 31% are included in this book. The papers were selected by the event chairs and their selection is based on a number of criteria that includes the classifications and comments provided by the Program Committee members, the session chairs' assessment, and also the program chairs' global view of all papers included in the technical program. The authors of selected papers from ICT4AWE 2017 were then invited to submit a revised and extended version of their papers having at least 30% innovative material.

The International Conference on Information and Communication Technologies for Ageing Well and eHealth aims to be a meeting point for those that study and apply information and communication technologies, and for improving the quality of life of the elderly and for helping people stay healthy, independent, and active at work or in their community along their whole life. ICT4AWE facilitates the exchange of information and dissemination of best practices, innovation, and technical improvements in the fields of age-related health care, education, social coordination, and ambient-assisted living. From eHealth to intelligent systems, and ICT devices, this is a point of interest for all those that work in research and development and across industries involved in promoting the well-being of elderly citizens.

"We have witnessed a rapid surge in assisted living technologies due to a rapidly aging society. The aging population, the increasing cost of formal health care, the caregiver burden, and the importance that the individuals place on living independently, all motivate development of innovative-assisted living technologies for safe and independent aging" (Rashidi and Mihailidis, 2013). Over the past few decades as our societies have been rapidly ageing, so too has the advancement of information and communication technologies (ICT). Yet the convergence of such target end users and new and innovate technologies has not always been fully realized. It has been far too common where the elderly have traditionally been an excluded group in the deployment of ICT (Neves and Amaro, 2012). However, more recently, there has been a growing paradigm shift in the utilization of ICT within an ageing society from a "nice to have" approach to a "need to have" philosophy. This was highlighted by Obi et al. (2013) where its survey clearly demonstrated that greater effort is needed to exploit ICT across a number of all domains (both societal and technological) in order to meet the challenges and needs produced by our rapidly ageing populations.

In that regard, the ICT4AWE has been a leading international conference in promoting the application of ICT across a number of innovative and meaningful methodologies to meet the real needs of our ageing societies. In the 2017 and third edition of ICT4AWE, the breadth and depth of the research and development presented clearly demonstrates the ever-increasing adoption of ICT across all domains within our societies, which clearly showcase that ICT can meet the "need to have" philosophy of our citizens for the twenty-first century and beyond.

In this book a number of innovative papers have made clear contributions in the area of ambient-assisted living (ALL) for the ageing. The papers selected to be included in this book contribute to the understanding of relevant trends of current research on "ICT for Ageing Well and eHealth," including: the collection and evaluation of day/night end user behavior patterns through the adoption of wearable technologies, i.e., "Laying the Foundation for Correlating Daytime Behaviour with Sleep Architecture Using Wearable Sensors" (Chapter 8). Such an approach can assist in the identification of end user activities, which may need greater attention to key behaviors by the end user themselves, caregivers, or health-care professionals, thus providing a higher quality of life.

In parallel, wearable technologies through smart textiles are playing an ever-increasing role in AAL as they provide a passive and natural linkage to ICT support systems, i.e., "What Is Hip? Classifying Adopters and Rejecters of Interactive Digital Textiles in Home Environments" (Chapter 1). In this survey paper, the identification and qualification of factors that influence the adoption or rejection of a smart textile was conducted and found that age in this regard had little or no bearing in the adoption of the smart textile artifact.

Finally, several studies have demonstrated that older adults often struggle with making the right decisions regarding meal preparation, healthy diets, or grocery shopping. In (Chapter 6) "SousChef: Improved Meal Recommender System for Portuguese Older Adults," the authors looked at end user needs as part of the nutrition in older adults. Moreover, an improved version of SousChef application, a meal recommender system, was presented, where new end user-specific heuristics were added to provide optional nutrition and variety. This book contains a diverse range of innovative, evidence-based papers that assist in the bridging of the gap between a nice to have approach to a need to have philosophy of ICT for ageing well.

We would like to thank all the authors for their contributions and also the reviewers who helped ensure the quality of this publication.

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April 2017

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Contents

What Is Hip? – Classifying Adopters and Rejecters of Interactive Digital Textiles in Home Environments

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Abstract. The omnipresence and familiarity of textiles in combination with the integration of invisible sensors, actuators, and information and communication technology under the term "interactive digital textiles" offer the potential of bridging the gap between age, the aging-population, and latest information and communication technology. Digital textiles are reaching maturity and first technology augmented cloths are becoming commercially available. However, little is known about the acceptance and projected use of digital textiles for/in home environments and whether acceptance is shaped by age, gender, expertise in interacting with technology, or other aspects of user diversity. In a survey with $n = 136$ participants, we identified and quantified factors that influence the adoption and rejection of a smart cushion as example for digital textiles. We found that attitude towards technology and attitude towards automation are decisive for the projected acceptance, while age plays a minor role. In addition, we provide a customer segmentation based on the projected use and provide detailed descriptions of adopters and rejecters as well as their model-based evaluations of the smart interactive cushion. The article concludes with open research questions and strategies for practitioners to leverage smart textile interfaces as basis for many innovative products in the future.

Keywords: Digital textiles · User diversity · Participatory design
Technology acceptance · Adopters & rejecters · Customer segmentation

1 Introduction

Mankind's history is inherently linked to the use of textiles and early traces of the use of textiles for clothing date back to 30.000 B.C. [1,2]. They give warmth and provide protection against the outside world, but they are also perceived

The original version of this chapter was revised: The spelling of the third author's name was corrected. The correction to this chapter is available at https://doi.org/10.1007/978-3-319-93644-4_11

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as pleasurable and fashionable. Thus, they are part of our everyday lives, for example as clothes and accessories, or as carpets and furniture surfaces.

On the other hand, the invention of the integrated circuit and consequently the microprocessor and advanced information and communication technology is a rather novel development and its consequences on the development of mankind can only be vaguely estimated. More than two and a half decades ago, Weiser and his team at Xerox Parc Palo Alto Research Center envisioned how office environments will evolve when information and communication technology grows in processing power and connectivity, while shrinking in size and cost [3]. They envisioned environments, in which smart computing technology is omnipresent, and framed this under the term “ubiquitous computing”.

In line with this development and building on humanity’s long history with textiles Post et al. incorporated sensors, actuators, and communication lines in textiles and ignited research on interactive textile interfaces [4,5]. Through progress in research and development digital textiles are reaching maturity and are on the brink of commercial application [6].

However, little is known on the individual’s perception of interactive digital textiles, perceived benefits and usage barriers, and who is likely to use interactive textiles. This work fills this void by providing an empirical modeling of user and system factors that shape the projected use and acceptance of iterative textiles, taking textile interfaces in the home environment as an use case.

Age as a key factor of user diversity receives particular attention in this work, as the aging population [7] in combination with lower information and communication technology (ICT) literacy of older people [8–10] yielded in a gray digital divide [11,12]. Thus, the development of novel, more sophisticated, and more complex information and communication technology might pose the unintentional risk of excluding elderly and jeopardizing their social integration and participation. Consequently, the diverse wants and needs of elderly must be addressed adequately throughout the design and development of novel interactive interfaces.

The article has the following structure: Sect. 2 presents the theoretical background of technical developments as well as acceptance research concerning interactive textiles. Section 3 describes our empirical approach to understand the perceived barriers and benefits of smart interactive textiles and to assess the user and system factors that govern acceptance by users. Section 4 shows the results of the empirical study starting with the general evaluation of the smart cushion and followed by a user-group specific description of the smart cushion’s evaluation. Section 5 provides a discussion and contextualization of the research findings as well as practical guidelines on the design and development of interactive textiles. Section 6 concludes this article by outlining a future research agenda.

2 Interactive Textiles and Acceptance

This section presents the state of the art in the domain of interactive textiles in Sect. 2.1, technology acceptance research in Sect. 2.2, and their combination (research on the acceptance of interactive textiles) in Sect. 2.3.

2.1 Technical Developments in Interactive Digital Textiles

Post et al. ignited research on interactive digital textiles by integrating sensors, actuators, power supply, and conductive yarn as signaling lines into fabrics [4,5]. Various projects built upon this work and developed textile interfaces for a multitude of usage scenarios ranging from cloths to furnitures [13]. In principle, every textile product can be augmented by ICT and the most common usage domains are wearables – i.e., when electronics are integrated into clothes – and furnitures. Consequently, the following two paragraphs briefly present related work from these two areas.

"Pinstripe" by Karrer et al. used parallel conductive yarns to detect folds and their movements in clothes two realize a two-dimensional continuous input device [14]. Users can pinch into the fabric of a T-Shirt, form a fold, and move the fold with their fingers up or down. The size of the fold and the movement can then be mapped on – for example – volume control with the size indicating the degree of change and the movement for the continuous adjustment. Building on that work, Hamdan et al. designed an interactive pad that allows grabbing cloth at different angels [15]. Integrated into a jacket, this interface might be used for eyes-free media control. PocketTouch by Saponas et al. used capacitive sensing to realize input detection on different textile surfaces [16]. Exemplary usage scenarios included the detection of small gestures up to the recognition of letters written on textile surfaces. To accelerate the development of textile interfaces Perner Wilson et al. introduced a toolkit to collect best-practice examples of digital textiles interfaces [17].

Multiple projects addressed the integration of interactive textiles in the home environment. For example, Heller et al. embroidered conductive yarns into curtain fabrics and realized a smart curtain [18]. By either touching or swiping orthogonally across the multiple sensing lines, a motor opened or closed the curtain. The integration of the conductive yarns offered room for visual design. The conductive yarn can either be embroidered in nearly invisible parallel lines or may be used as creative element in form of more complex visual ornaments. Rus et al. built and evaluated a smart textile sofa by integrating electrodes in several spots across its surface [19]. Using data from the sensors the sofa was able to perform reliable posture detection.

Recent advances by Poupyrev et al. demonstrated that the integration of conductive yarns can be realized in industrial weaving processes, thus allowing the manufacturing of interactive textiles at scale and with reasonable costs [6]. However, it is still unclear which individuals are inclined towards interactive textiles and what factors shape the individual's assessment of this novel technology. Technology Acceptance Research is the methodology to resolve these questions and will be presented in the following section.

2.2 Empirical Modeling of Technology Acceptance

Technology Acceptance Research aims at understanding what shapes the adoption and rejection of novel technologies. A milestone within this research domain is Davis' Technology Acceptance Model (TAM) [20]. TAM predicts the *intention to use* and later *use* of software systems using the three constructs *perceived ease of use*, *perceived usefulness*, and *attitude towards using*. Based on Davis' TAM and other extended models Venkatesh et al. [21] adapted the concept of linking system evaluations with the intention to use to predict the use of consumer technology – the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2). The model builds on the seven dimensions *Performance Expectancy* (PE), *Effort Expectancy* (EE), *Hedonic Motivation* (HM), *Social Influence* (SI), *Facilitating Conditions* (FC), *Price Value* (PV), and *Habit* (HB) and is able to predict almost 74% of the *intention to use* concerning a specific technology and about 52% of actual use after four months.

2.3 Acceptance Research on Interactive Textiles

So far, only occasional studies have been conducted focusing on technology acceptance of interactive textiles, due to the novelty of this technology. In the following section, an overview of the few existing studies and their results is given.

Holleis et al. provided first qualitative insights by investigating diverse input modes for media player control on different prototypical input devices. In more detail, the preferred design of interaction (e.g., visible vs. invisible buttons, ornaments) and preferred body locations for performing gestures (e.g., hands, legs, chest) were focused [22].

A further study examined the acceptance of wearable smart textiles in different usage contexts using a scenario-based approach [23]. The study revealed an influence of different usage contexts on the evaluations of smart textiles (leisure contexts (i.e., sports) vs. medical contexts (i.e., monitoring vital parameters)) as well as an influence user diversity (age, previous experiences, and the individual knowledge about the technology).

Furthermore, a conjoint-based approach was used by Hildebrandt et al. to identify which product features influence the general acceptance of smart digital textiles most [24]. The study revealed that the technical realization of these products was most important as users disliked noticeable electronics in the devices and preferred a seamless integration into the textile. The second important factor was the room, in which the textile was used (living room preferred; bedroom and kitchen declined). The factor functionality (i.e., what the interactive textile should be able to do) was less, while the factor wearability was comparatively least important with a slight participants' preference towards interactive textiles that are integrated into non-wearable devices (e.g., curtains, cushions).

Another study deepened the comparison of wearable and non-wearable devices in order to understand specific requirements for textile input devices within home environments [25]. In a questionnaire study with 72 participants in an age range between 20–76 years the perceived benefits and barriers of smart textiles in the home context were explored, but also the requested functions to be controlled by textile input devices as well as the type of devices and the specific home locations. Results showed that participants do not see much benefit in the use of textile input devices, but – on the other hand – the barriers are also not that prominent what might be due to the fact that almost none of the sample already had hands-on experience with smart textiles. However, participants expressed a number of important conditional usage criteria that should be guaranteed first before they would use smart textiles. The most prominent conditionals were a high usability and ease of using the textiles, whereas the material quality, the functionality, and the ease of cleaning were of lower importance. With respect to the device type, the study showed that participants favor table surfaces, chairs or sofas, and outerwear for integrating interactive textile interfaces over smart carpets or curtains. The desired functions that should be controllable by smart textiles (e.g., switching TV or music channels, control interior lighting) related especially to textiles in the living room and the office, which were the most preferred home locations for participants. In contrast, smart textiles were seen as not useful in the kitchen and bedroom [25].

A follow-up study with 90 participants investigated motives, barriers, and conditions for using interactive digital textiles in an aging context. It was of interest if the acceptance of smart textiles is different for persons of different generations. In detail, different usage contexts of interactive textiles (i.e., bedroom, living room, kitchen, and integrated in clothes) [26] were investigated. Results showed that – across all conditions explored – age and generation of participants did not impact the acceptance of smart textiles, revealing a quite unique view on smart textiles. In single areas, though, age effects showed up: With respect to the question of the longevity of smart textiles, a significant age effect was found: Younger adults had significantly higher demands on longevity than middle-aged and the older participants. Another age effect was revealed in the opinion that smart textiles would complicate lives – a belief that was more frequently confirmed by older adults. Overall, the study revealed that the use of smart textiles seems not to be different for older and younger adults, thus revealing that the technology is basically appropriate for a broad user group.

In contrast to scenario-based approaches, an usability study with smart interactive textiles was also conducted [6] focusing on the recognition rates of gestures (swipe right, swipe left, hold) taking different use conditions into account (sitting, walking, standing) and using small interactive areas of a test jacket's sleeve. The study revealed an overall recognition rate of almost 77%, although the recognition rate varied significantly depending on the use conditions under study.

Summarizing previous studies on the acceptance of interactive textiles, smart textiles were especially accepted and desired in the home environment's and specifically the living room. Furthermore, user diversity seemed to influence their acceptance. Strikingly, previous research in the field of smart interactive textiles predominantly focused on smart wearable textiles, while research on non-wearable smart textiles – such as furnitures, bed linen, or pillows and cushions – in home environments is comparatively rare.

Consequently, this article focuses on the overarching research question if these effects are also present for smart textile interfaces in home environments and which evaluation dimensions govern the users' acceptance. Based on preceding studies and specifically findings of focus groups, we specified a smart cushion as an application scenario, whereby the cushion can be placed in the living room, for example on the sofa or armchair. Gestures on the cushion can be used to control music or light within the home environment. The following section precisely describes the underlying methodological approach.

3 Method

This section presents the study's methodological approach starting with a description of the applied research's design, followed by specifications of the applied statistical procedures, and the sample of the study. The goal of this study was to analyze whether an adapted acceptance model could be used for evaluating the acceptance of a specific smart interactive textile and if there are user groups that differ in their acceptance behavior. The following central research questions guided the design of the study:

1. Is the Unified Theory of Acceptance and Use of Technology 2 model (see Sect. 2.2) suitable to predict the likely adoption of a smart cushion as an example for smart interactive textiles in the home environment?
2. Do user groups with different patterns of adopting and rejecting the smart cushion exist? What characterizes these user groups?
3. Do the key usage motives differ for diverse user groups?

3.1 Design of Applied Research Approach

We chose the method of a paper-and-pencil questionnaire in order to reach similarly younger and older participants. The items of the questionnaire were based on the UTAUT 2 model, but were adjusted to the context of smart textile interfaces. Further, the model was extended by constructs based on the findings of several focus groups consisting of five people carried out prior to this study.

Within the first part of the questionnaire, participants' *demographic characteristics* (age, gender, educational level) were addressed and we also asked for more detailed user-specific aspects such as participants' health status (e.g., chronic diseases and physical restrictions). Additionally, the participants evaluated their previous experience with smart textiles (using two items; $\alpha = .79$).

In the next part, the participants were asked for their *attitudes towards technology* (TECH), towards *textiles* (TEX), and towards *automation* (AUTO), whereby respective items were summed up for each construct and checked for item and scale reliability. The *attitudes towards technology* was measured based on Karrer et al. capturing the following four dimensions: *technical enthusiasm* (EN), *experience of technical competency* (COMP), and *positive* (POS) as well as *negative* (NEG) *experience* with technology with three items for each dimension [27]. The *self-efficacy in interacting with technology* (SET) was measured on a scale by Beier [28] (using four items; $\alpha = .82$). In accordance with

Bandura, domain specific self-efficacy refers to an individual's confidence to execute a specific behavior or to attain a specific goal [29] and various studies found an significant influence of domain specific technical self-efficacy on interacting with computing technology [8–10]. As no validated scale for a measurement of the *attitude towards textiles* (TEX) has been applied so far, we built a new scale with four items based on previous findings from our preceding focus group studies. The results revealed that this scale achieved a sufficiently high internal reliability for a newly developed scale (four items; $\alpha = .66$). Furthermore, AUTO was queried (using six items; $\alpha = .83$) also derived from the results of previous qualitative studies.

After the assessment of personal and attitudinal information, the participants were asked to conceive a scenario, in which a cushion lied on the sofa in the living room and functioned as a remote control for the domestic electronic devices such as light, music, and heating in the whole home environment. The participants should imagine that electronic sensors were incorporated in the cushion enabling to respond to different hand gestures, e.g., operating by stroking, kneading, grabbing, or rolling and twisting of folds.

Using the scenario, the participants envisioned the smart cushion and its functions and then evaluated the acceptance of the cushion based on the adapted UTAUT2-model [21]. Our *STTAM – Smart Textile Technology Acceptance Model* – incorporated the dimensions *Intention To Use* (ItU), *Performance Expectancy* (PE), *Effort Expectancy* (EE), *Hedonic Motivation* (HM), *Social Influence* (SI), *Facilitating Conditions* (FC), *Price Value* (PV), and *Habit* (HB) from UTAUT2. Further, the model was complemented by the dimensions *Washability* (WASH) and *Technical Conditions* (TC) (capturing technical aspects such as long durability or input efficiency) based on the results of previous qualitative studies. The participants assessed the respective dimensions using each three or four items on six-point Likert scales (0 = strongly disagree; 5 = strongly agree).

Completing the questionnaire took about 15 min and data was collected in Germany in spring 2015. The participation was voluntary and not gratified.

3.2 Applied Statistical Procedures

Data was analyzed using bi-variate correlations of model- and user-related factors, Pearson's χ^2, uni- and multivariate analyses of variance (ANOVA/MANOVA) as well as linear regressions. The level of significance was set to $p = .05$. Spearman's ρ was used for bivariate correlations and Pillai's V was stated for the omnibus test of MANOVAs. The effect size was reported as partial η^2. The step- wise method was used in the multiple linear regression and models with low standardized β were removed between the runs. Models with high variance inflation ($VIF \gg 1$) were excluded. The whiskers in the diagrams indicate the standard error. For the two-step cluster analysis the silhouette coefficient was $>.5$, indicating a good separation between and a good cohesion within the clusters. $\pm$ indicates the standard deviation.

3.3 Participants

The questionnaires were distributed on paper in a rural area and a total of 136 people participated voluntarily in this study. 12 (8.8%) incomplete datasets were excluded and only complete datasets were considered in the subsequent analyses.

The final sample consists of 56 male (45.2%) and 68 female (54.8%) participants with an age range from 17–86 years, an arithmetic mean of 49.5 ± 16.2 years and a median age of 53.0 years. The sample's educational level is heterogeneous, as 29.3% reported holding a secondary school certificate, 26.6% an university entrance diploma, and 27.4% completed junior high school. Chronic diseases affect only a small share of the participants (14.8%) and include mainly diabetes or allergies. About half of the participants (50.4%) reported owning a pet (48.7% reported no pet ownership). None of the factors (educational level, health status, pets) was associated with age or gender.

Besides these demographic information, the participants were asked for their technology attitude and experience in five dimensions: the participants showed a positive *Perceived Competency* in interacting with technology ($M = 3.7 \pm 1.2$; $min = 0$; $max = 5$), a rather positive *self-efficacy in interacting with technology* ($M = 2.9 \pm 1.2$; $min = 0$; $max = 5$), and a slightly positive perceived technology *Enthusiasm* ($M = 2.7 \pm 1.5$; $min = 0$; $max = 5$); On average, the participants confirmed a *Positive Attitude Towards Technology* ($M = 3.3 \pm 1.0$; $min = 0$; $max = 5$), while they rated *Negative Attitude Towards Technology* ($M = 2.5 \pm 1.2$; $min = 0$; $max = 5$) neutrally. Further, the participants reported a positive *Attitude Towards Textiles* (TEX) ($M = 3.4 \pm 1.1$; $min = 0$; $max = 5$) and a slightly positive *Attitude Towards Automation* (AUTO) ($M = 2.9 \pm 1.6$; $min = 0$; $max = 5$). In contrast, previous experience with smart interactive textiles was very low ($M = 0.7 \pm 1.3$; $min = 0$; $max = 5$).

Analyzing potential relationships of user and attitudinal factors, a correlation analysis revealed significant correlations between gender (dummy coded as $0 = male, 1 = female$) and SET ($\rho = -.39$, $p < .01$, sig.), gender and TECH ($\rho = -.314$, $p < .05$, sig.), gender and TEX ($\rho = .25$, $p < .01$, sig.) as well as gender and AUTO ($\rho = -.26$, $p < .05$, sig.). Hence, women reported to be less inclined to technology than men, however, woman were more inclined to textiles than men. Further, age correlated significantly with SET ($\rho = -.33$, $p < .01$, sig.) as well as TECH ($\rho = -.28$, $p < .01$, sig.). The elderly indicate to be less inclined to technology than younger participants. In contrast, age was not related to AUTO ($\rho = -.14$, $p = .11 > .05$, n.s.) and TEX ($\rho = .02$, $p = .80 > .05$, n.s.).

4 Results

This section presents the results of the present research approach starting with the overall evaluation of the smart cushion. Afterwards, distinct clusters of users are identified in regard to in acceptance behavior and characterized concerning their differences in user factors. Subsequently, the user group specific evaluation of the smart cushion based on the adapted acceptance model is described.

4.1 Model-Based Evaluation of a Smart Cushion

A previous study revealed that the *Intention to Use* (ItU) the smart interactive cushion was evaluated slightly negative by the participants ($M = 2.1 \pm 1.5$; $min = 0$; $max = 5$) and that all considered model dimensions were associated with the *Intention to Use* (ItU) [30]. Especially the dimensions PE, HM, and HB were strongly related with ItU. The dimensions SI, FC, PV, and TC were also significantly but on a slightly lower level correlated with ItU. EE and WASH had the comparatively lowest impact on ItU (see Table 1).

A step-wise multiple regression analysis was conducted in order to find out which model dimensions were the key predictors for the acceptance of the smart cushion. For this, the evaluation dimensions represented the independent and the ItU dimension the dependent variable. The analysis revealed three significant models: the first model predicted 83.5% variance of ItU $r^2_{adj.} = .835$ with the dimension *habit (HB)* as key predictor; the second model predicted 85.9% variance $r^2_{adj.} = .859$ based on *HB* and additionally *hedonic motivation (HM)* as key predictors; and finally, the third model predicted 86.2% ($r^2_{adj.} = .862$) with *HB*, *HM*, and *performance expectancy (PE)* as predictors. Table 2 illustrates the final regression model for the evaluation of the smart cushion referring to the whole sample.

Table 1. Inter-correlations of user factors (bottom) and the product's evaluation (upper) on the Smart Textile TAM dimensions (PE = Performance Expectancy, HM = Hedonic Motivation, HB = Habit, EE = Effort Expectancy, SI = Social Influence, FC = Facilitating Conditions, PV = Price Value, WASH = Washability, TC = Technical Conditions, ITU = Intention To Use, TECH = Attitude Towards Technology, TEX = Affinity Towards Textiles, AUTO = Attitude Towards Home Automation). † = $p < .1$, * = $p < .05$, ** = $p < .001$ (see [30]).

	PE	HM	HB	EE	SI	FC	PV	WASH	TC	ITU
PE	—	.689**	.755**	.348**	.553**	.520**	.335**	.351**	.367**	.764**
HM		—	.765**	.313**	.534**	.577**	.373**	.335**	.549**	.791**
HB			—	.281**	.662**	.649**	.445**	.357**	.493**	.904**
EE				—	.167†	.514**				.207*
SI					—	.460**	.363**	.299**	.313**	.655**
FC						—	.342**	.231*	.337**	.606**
PV							—	.246**		.459**
WASH								—	.182*	.304**
TC									—	.488**
Age				−.236**					.176†	
TECH	.268**	.288**	.293**	.430**	.155†	.407**			.175†	.327**
TEX		.302**		.156†					.280**	
AUTO	.342**	.343**	.398**	.307**	.197*	.372**	.192*		.198*	.491**

Table 2. Linear regression for Intention To Use (ItU) based on HE (Habit), Hedonic Motivation (HM), and Performance Expectancy (PE) ($r^2_{adj.} = .862$) (see [30]).

Model	B	SE B	β	T
(const)	−.614	.129	—	−4.761
HB	.664	.070	.633	9.542
HM	.272	.070	.237	3.876
PE	.136	.068	.114	2.015

In preceding analysis processes, we found significant correlations of several user diversity factors with ItU and other model dimensions (see Table 1): For instance, the individual attitudes TECH and AUTO were related with ItU (as well as almost all model dimensions) showing that participants who reported to be more inclined with technology and to have higher wishes for automation showed a more positive *Intention to Use* the smart interactive cushion. However, the analysis revealed no significant correlations of age, gender, and TEX with ItU. Although these results deliver insights into single relevant user diversity factors, they do not support to understand in depth who adopts and who rejects the cushion as example for smart interactive textiles.

4.2 Identification of Adopters and Rejecters

To understand the different perceptions of people who are likely to accept or reject smart interactive textiles we segmented the sample by their usage intention. We calculated a two-step cluster analysis with two target clusters based on the three variables capturing the overall *Intention to Use* the smart interactive textile. Overall, this procedure yielded in a good separation between the two clusters and a good cohesion within the clusters (silhouette coefficient >.5).

As Fig. 1 (left) illustrates, the cluster membership had an obvious and strong effect on the *Intention to Use* (ItU) the smart cushion: the first cluster contained 64 participants with a low *Intention to Use* ($M = 0.8 \pm 0.6$; $min = 0$; $max = 5$) and will be referred to as "*rejectors*", while the second cluster contained 59 participants with a high *Intention to Use* and will be referred to as "*adopters*" ($M = 3.3 \pm 1.0$; $min = 0$; $max = 5$).

As Table 3 shows, neither age ($\rho = -.018$, $p > .05$), nor gender ($\chi^2 = 1.294$, $p > .05$) are linked to cluster membership. Instead, the personal attitudes TECH and AUTO were related to the membership of the clusters: the group of *adopters* showed a significantly more positive attitude towards technology and automation than the group of *rejecters*. In contrast, TEX was not significantly related with the cluster membership.

4.3 Differences in the Smart Cushion's Evaluation

The cluster membership had a significant and strong effect on each of the STTAM evaluation dimensions ($V = .623$, $F_{9,107} = 19.647$, $\eta^2 = .623$, $p < .001$)

Table 3. Characterization of Intention to Use (ItU) clusters (AUTO = Attitude Towards Home Automation, TEX = Affinity Towards Textiles, TECH = Attitude Towards Technology).

	Adopter	Rejecter	Significance
Sex	32m/32w	28m/38w	$\chi^2 = .750$, $p = .482 > .05$
Age	48.9 ± 16.2 (17–78 years)	49.4 ± 15.9 (18–86 years)	$F_{1,124} = 0.347$, $p = .557 > .05$
TECH	3.1 ± 0.8	2.7 ± 0.8	$F_{1,124} = 11.146$, $p < .01$
AUTO	3.7 ± 1.2	2.2 ± 1.6	$F_{1,124} = 31.682$, $p < .001$
TEX	3.5 ± 1.1	3.4 ± 1.1	$F_{1,124} = 1.059$, $p = .305 > .05$

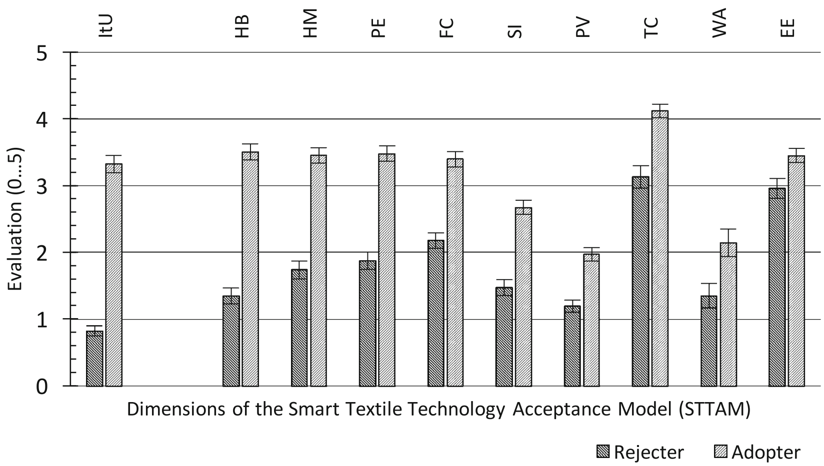

Fig. 1. Evaluation of the smart cushion on the Smart Textile TAM dimensions by usage intention clusters (adopters and rejecters) ordered by effect size (whiskers indicate the SE, PE = Performance Expectancy, HM = Hedonic Motivation, HB = Habit, EE = Effort Expectancy, SI = Social Influence, FC = Facilitating Conditions, PV = Price Value, WASH = Washability, TC = Technical Conditions, ItU = Intention To Use).

and likely adopters evaluated each of the dimensions higher than the likely rejecters. Figure 1 (right) shows the differences between *rejecters* and *adopters* in regard to the evaluation dimensions ordered by the η^2-effect size form highest (left) to lowest (right).

Cluster membership unfolded the strongest influence on the perceived ability to use the technology regularly (HB: $F_{1,115} = 154.675$, $\eta^2 = .574$), $p < .001$). The second strongest effect was found on the perceived enjoyment using the technology (HM: $F_{1,115} = 95.198$, $\eta^2 = .453$, $p < .001$). *Rejecters* and *adopters* also evaluated the perceived usefulness and the perceived gain in abilities of the technology differently (PE: $F_{1,115} = 74.831$, $\eta^2 = .394$, $p < .001$). The influence of the cluster membership on the perceived facilitating conditions, e.g., if the technology is embeddable in the current environment, was strong as well

(FC: $F_{1,115} = 57.883$, $\eta^2 = .335$, $p < .001$). This was also true for the dimension social influence (SI: $F_{1,115} = 53.655$, $\eta^2 = .318$, $p < .001$). A less stronger influence was unfolded on the perceived price-value trade-off of the technology (PV: $F_{1,115} = 28.496$, $\eta^2 = .199$, $p < .001$) as well as on the technology's technical conditions (TC: $F_{1,115} = 24.864$, $\eta^2 = .178$, $p < .001$). The second lowest influence of cluster membership was found for the perceived washability of the smart cushion and although rejectors and adopters evaluated the washability differently, the effect was rather small ($WASH$: $F_{1,115} = 9.514$, $\eta^2 = .076$, $p = .003 < .05$). Surprisingly, the perceived difficulty to learn using the technology and the later continuous usage was the dimension with the lowest, yet significant, effect of the cluster membership (EE: $F_{1,115} = 6.454$, $\eta^2 = .053$, $p = .012 < .05$).

Correlation Analysis. To understand the relationships of the cluster membership and the model dimensions, correlation analyses were conducted. Tables 4 and 5 illustrate the respective results. Concerning the group of *adopters* (Table 4), the dimensions *HB*, *HM*, and *PE* were strongly related with the ItU a smart cushion and also with almost all other model dimensions. Further, *TC, FC, EE, SI,* and *PV* had a lower influence on *ItU*. In contrast, *WASH* was the only dimension that did neither correlate with the ItU nor the other model dimensions.

Referring to the group of *rejecters* (Table 5), the results revealed a clearly lower number of correlations as well as weaker correlations. The model dimensions *HB, PE,* and *HM* were again strongly related with *ItU*, though clearly on a lower level than for the *adopters*. The dimensions *SI, WASH,* and *TC* were comparably weaker related with *ItU*. However, the dimensions *EE, FC,* and *PV*

Table 4. Correlations of the product's evaluation for the *adopter* user group on the basis of the Smart Textile TAM dimensions (PE = Performance Expectancy, HM = Hedonic Motivation, HB = Habit, EE = Effort Expectancy, SI = Social Influence, FC = Facilitating Conditions, PV = Price Value, WASH = Washability, TC = Technical Conditions, ItU = Intention To Use). $^{\dagger}= p < .1$, $* = p < .05$, $** = p < .001$.

	PE	HM	HB	EE	SI	FC	PV	WASH	TC	ItU
PE	—	.600**	.664**	.492**	.338**	.356**			.333**	.631**
HM		—	.814**	.467**	.329**	.640**	.224†		.629**	.839**
HB			—	.513**	.332**	.558**	.307**		.515**	.888**
EE				—		.464**			.316*	.416**
SI					—	.258*	.311*			.340**
FC						—			.257*	.514**
PV							—			.322*
WASH								—		
TC									—	.541**
Age								.228†	.235†	

Table 5. Correlations of the product's evaluation for the *rejecter* user group on the basis of the Smart Textile TAM dimensions (PE = Performance Expectancy, HM = Hedonic Motivation, HB = Habit, EE = Effort Expectancy, SI = Social Influence, FC = Facilitating Conditions, PV = Price Value, WASH = Washability, TC = Technical Conditions, ITU = Intention To Use). $^{\dagger} = p < .1$, $* = p < .05$, $** = p < .001$.

	PE	HM	HB	EE	SI	FC	PV	WASH	TC	ItU
PE	—	.571**	.505**		.321**			.374**		.555**
HM		—	.496**		.381**			.342**	.328**	.514**
HB			—		.537**	.281**		.423**	.281**	.688**
EE				—		.498**				
SI					—					.474**
FC						—		.278*		
PV							—		−.234†	
WASH								—		.282**
TC									—	.252**
Age				−.350**		−.307*				

were neither related with *ItU* nor had they a strong influence on all other model dimensions as they each correlated with only one dimension.

Regression Analysis. In order to understand which model dimensions predict the ItU of the smart interactive cushion and if these dimensions differ with regard to *adopters* and *rejecters*, we calculated step-wise multiple regression analyses for each group. In the following, the calculated final models are described and illustrated (see Table 6 (left side: *rejecters*; right side: *adopters*)).

Considering the group of *adopters*, the final model predicted 81.4% variance in ItU ($r^2_{adj} = .814$) and was explained by the dimensions *habit (HB)* and *hedonic motivation (HM)*. In contrast, the final regression model for the group of *rejecters* predicted 50.5% and thus a clearly lower proportion of variance in ItU based on the dimensions *habit (HB)*, *performance expectancy (PE)*, and *effort expectancy (EE)*.

5 Discussion

Interactive digital textiles are a promising development and the brink at commercial exploitation. To fully harness their potential, we need to understand what shapes individual's acceptance and rejection. By using a scenario-based approach with a smart cushion as example for smart interactive textiles in the home environment, this study investigated the acceptance of smart textiles using an adapted version of the UTAUT2 model specifically tailored to smart textiles (Smart Textile Technology Acceptance Model, STTAM). This section provides a discussion of the results and answers to the research questions that represented the basis for the conducted study (see Sect. 3).

Table 6. Linear regression models for Intention To Use (ItU) for likely *adopters* and *rejectors* of smart interactive textiles in home environments.

Model	B	SE B	β	T
(const)	.349	.171	—	2.038
HA	.343	.068	.535	5.080
PE	.167	.061	.291	2.739
EE	-.100	.047	−.195	−2.119

(a) Rejectors ($r^2_{adj} = .505$)

Model	B	SE B	β	T
(const)	-.258	.240	—	−1.077
HA	.702	.103	.651	6.804
HM	.324	.104	.298	3.121

(b) Adopters ($r^2_{adj} = .814$)

5.1 Suitability of the Applied Acceptance Model

First, the results indicate that the model used in this study is able to capture the overall intention to use the smart cushion. All dimensions from the underlying UTAUT2 model and the newly integrated additional dimensions *washability* of the textile and *technical conditions* significantly and profoundly relate to the intention to use the product (see also [30]).

As of now, the smart cushion is neither realized as a functional demonstrator nor as a salable product. Hence, the postulated relationship between the model's constructs, the captured intention to use, and the final use of a product in the future cannot yet be formally established. However, based on previous work by Fishbein and Ajzen [31,32], Davis [20], and Venkatesh et al. [21], we assume that the strong relationship between intention to use and actual use will also emerge for smart interactive textiles.

5.2 Classification of Adopters and Rejecters

The cluster analysis revealed two existing participant groups with clearly significant differences in their acceptance behavior and attitudes towards the smart cushion as an example for smart interactive textiles. Further, the groups were characterized by differences with regard to attitudinal variables, i.e. attitude towards technology and attitude towards automation: participants with higher acceptance and intention to use the smart interactive textile (adopters) had a more positive attitude towards technology and automation. The classification based on acceptance and not on single user factors enables to compare and understand people with distinctive differences in their behavior.

5.3 Evaluating Differences in Usage Motives

The regression analysis results gave insights into similarities and differences with regard to the evaluation of model dimensions by the clustered groups. In the following we utilize these results to derive empirically grounded communication guidelines for introducing digital textiles to both groups.

General Communication Guidelines. Results showed that the dimension *habit (HB)* was part of every model (whole sample, adopters as well as rejecters) and had in each analysis the comparatively strongest influence on the intention to use the smart cushion. Thus, it is of major importance for all participants, that they are able to envision to use the product on a regularly basis and so, increasing the behavioral intention to use the smart cushion requires to increase the perceived habit. Some ideas for realizing an increased perceived habit are based on Bandura [29] suggesting role models who are able to show the opportunities and benefits of smart interactive textiles facilitating certain daily activities as well as friends and family members who are able to persuade people to integrate novel products into their everyday life.

Addressing Adopters. In contrast, there were also some considerable differences in the regression models for adopters and rejectors. For the group of adopters, the *hedonic motivation (HM)* was the second influencing usage motive: if they attest the usage of the smart cushion is fun, this influences their intention to use and acceptance of the smart cushion. Hence, this second strongest predictor should be considered during the design of novel input devices, which should not only focus on usability measures, but also integrate aesthetics and the perceived fun when using these devices. Interestingly, the model for the *adopters* group, showed a high share of explained variance (81.4%) similar to the model referring to all participants.

Addressing Rejecters. However, the regression model for the *rejecters* group predicted a clearly lower share of variance (50.5%). This suggests that this group had the more negative attitude towards the smart cushion due to the clearly lower enthusiasm and more negative attitudes towards technology in general and towards automation. Differences were not only found for the share of variance but also in the predicting motives: for the *rejecters*, the second and third predictors of acceptance and behavioral intention to use the cushion are *performance expectancy (PE)* and *effort expectancy (EE)*. Therefore, these two aspects have to be addressed in order to increase the acceptance of this user group. Referring to *performance expectancy (PE)*, we assume that this dimension refers to perceived benefits of technology usage. For the smart cushion, clear examples should be provided focusing on what the smart cushion can be used for in the personal environment (e.g., light of the living room, music, or television can be adjusted to the individual mood by using an intuitive swipe gesture on the cushion). Referring to *effort expectancy (EE)* information should be provided on how the cushion has to be controlled and which gestures should be used in order to allay concerns about an arduous and complex handling of the smart cushion.

These results show that prototypical adopters and rejecters have to be addressed in each case adapted to their individual needs (as suggested) in order to satisfy their respective system requirements.

5.4 The Role of Age in the Context of Interactive Digital Textiles

Aging is usually associated with lower perceived usefulness, perceived ease of use, perceived usage satisfaction, and perceived and actual effectiveness when interacting with a wide range of electronic devices—ranging from computers, ticket machines, to mobile phones and tablets [9,10].

In contrast to a prior study [23], in which significant influences of user diversity factors (in particular age) were found with regard to the evaluation of use requirements of smart interactive textiles, the overall acceptance behavior was not influenced by age in this study.

Neither was the overall acceptance behavior (intention to use) affected by age, nor did age unfold significant influence of the models variables. Merely, effort expectancy and facilitating conditions were influenced for the group of rejecters and washability and additional technical conditions for the group of likely adopters. Consequently, age plays a minor role in the likely adoption or rejection of these novel technologies. However, if the product's adoption by elderly should be facilitated, these four dimensions might be targeted.

5.5 Limitations and Future Research

The study used a scenario-based approach and the results are therefore shaped by the participant's ability to imagine the form, feeling, and functioning of the smart textile. Consequently, future work should investigate the user's perception of tangible and functional demonstrators. Ideally, the long term adoption and usage of smart textile-based interfaces in the home environment is evaluated and the relationship between user and model constructs, intention to use, and later actual use is precisely quantified in an empirical model.

As already addressed before, the study focused on a specific smart interactive textile example – the smart cushion. Besides this product, it is also of importance to evaluate other product examples with different application contexts. We used the cushion as an scenario-based example for a smart textile in the home environment. In current and future studies, we focus and will further focus on different products with diverse ranges of functions in order to understand which determinants for later use are universal and which are product-specifically relevant. Within our interdisciplinary research project on smart interactive textile surfaces, we have already developed first demonstrators for different usage contexts: an interactive curtain, a smart jacket, and a smart armchair [33]. First usability studies found the demonstrators (curtain and armchair) to be very intuitive and easy to use (high ease of use), whereas the participants attested the armchair a higher usefulness compared to the curtain. Further versions of prototypical demonstrators are currently on a testing stage and will be evaluated in the near future.

In addition, there are some limitations with regard to the sample of the present study, which was rather small. Hence, we aim for a replication of this study's design and will try to reach a greater and more representative sample especially referring to age. The present study tried to reach older participants leading to a comparatively "old" sample due to the paper-and-pencil questionnaire, which was very useful in order to analyze older participants' needs and wishes towards smart interactive textiles. In contrast, it would be useful and desirable to reach a balanced age-distribution covering all age groups in future studies.

6 Conclusion

The article investigated the projected acceptance of interactive digital textiles using a scenario-based approach and an envisioned smart cushion as an example. The study with $n = 136$ participants shows that age is not decisive for projected acceptance, however that attitude towards technology and attitude towards automation are rather strong determinants for acceptance.

One key finding of this work is that interactive digital textiles are perceived differently than other forms of novel information and communication technology: Elderly people usually report lower literacy and competency in interacting with ICT [8–10] which often yields in lower usage and participation and thus a gray digital divide [11].

Why wasn't this the case for interactive textiles? The omnipresence of textiles in our everyday lives, their deep rooting in mankind's history, their softness, and their warmth may offer a novel approach to design information and communication technology that seamlessly blends into the people's habitats and may include younger and older people alike. Especially in regard to the development of ambient assisted living environments and smart homes [34–36], smart interactive digital textiles may consequently act as a viable solution to bridge the gray digital divide and to facilitate intuitive, gentle, and pleasurable interactions by everybody.

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Living with Disabilities – The Many Faces of Smart Home Technology Acceptance

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Abstract. To face the challenges of increasing care needs due to demographic change, the development of smart home and Ambient Assisted Living (AAL) technologies present one approach, which is continuously forwarded. Besides aspects of technical development and implementation, user acceptance of diverse stakeholders plays a major role for a successful rollout and sustainable adoption of those technologies. So far, user acceptance research in this context has concentrated mostly on age-related issues. In contrast, disabilities and related care needs have hardly been researched yet. The current study focused on persons having different experiences with disabilities and care needs. In a qualitative interview pre-study (n = 9) and a follow-up quantitative online questionnaire study (n = 279) perceived benefits and barriers, use conditions, and acceptance of AAL technologies were contrasted. Four user groups were under study: disabled participants, relatives of disabled persons, professional caregivers, and, as a control group, persons without experience with disabilities. Results indicate that disabled and care-needy people show a higher acceptance and intention to use an AAL system than not-experienced people and especially professional caregivers. The motives for acceptance and rejection differ strongly regarding user diversity as well. The results contribute to a better understanding of user-specific acceptance of smart home and AAL technologies and show that the integration of diverse user groups into the technologies' design and evaluation process is necessary.

Keywords: Technology acceptance · User diversity
Ambient assisted living (AAL) · Smart home technologies
Needs of assistance and care · Experience with disabilities

1 Introduction

Diseases and disabilities are omnipresent challenges for today's society. Particularly in the context of demographic change, a steadily increasing number of older people and people in need of care pose strains for the care sectors [1, 2].

Coincidently, most of the older people desire to live at their own home as long and as autonomously as possible [3]. Hence, connected with the rising age of people and their willingness to stay at home as long as possible, age-related diseases (e.g., cardiovascular diseases, diabetes, or dementia) are greatly relevant and rise continuously [4–6]. However, they represent only one side of the coin as age-independent diseases

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and disabilities are also of importance causing huge needs of care and assistance as well [7]. Further, a new phenomenon of a first generation of "old and disabled" people needs to be taken into account: on the one hand, this development is enabled by medical and technical innovations in healthcare, e.g., new medicines and inventive therapies; on the other hand, this development is also influenced by the specific historical background of euthanasia offenses (especially in Europe), in which disabled people were systematically aborted, deported, and even murdered [8].

Summarizing, age, diseases, as well as disabilities must be considered while analyzing increasing needs of care and related challenges. Yet, there are technical single-case solutions and complex ambient assisted living (AAL) or smart home technology systems [9] that address these challenges. These developments already enable systems that monitor (medical) parameters, detect falls and positions, or facilitate living at home using smart home technology elements [10–12]. Besides technical single-case solutions, current research focuses also more and more on holistic systems, that unite different functions and are especially adaptable to individual needs of diverse user groups.

To realize technical systems that meet the requirements of diverse user groups, it is necessary to analyze whether, to which extent, and under which conditions such systems are accepted and also to what extent those evaluations depend on user factors. So far, there have been several studies investigating the acceptance of AAL and smart home technologies focusing on influencing demographic factors such as age (e.g., [13, 14]) or gender [15]. As disabled people have hardly been considered yet, this paper analyzes the acceptance of AAL systems with focus on people having different perspectives and experiences with disabilities.

2 Smart Home Technologies and Acceptance

This section illuminates the technical and acceptance-relevant historical background for the underlying research approach. First, the most important developments concerning AAL and smart home technologies are summarized. Further, key aspects of the theoretical background with regard to technology acceptance research is presented focusing on potential influencing user diversity factors. Finally, an overview of current acceptance research on AAL systems and the starting point for the underlying research approach are given.

In the last decades, the use of Information and Communication Technologies (ICT) in everyday life has been studied [16] and different options of monitoring are enabled by integrating ICT (e.g., microphones, cameras, and movement sensors) into people's living spaces. To date, the amount of commercial smart home technology systems as well as smart home and AAL research projects increased continuously. These systems enable smart home functions (e.g., sensors for lighting and heating control, sensors for automatic opening of doors and windows), fall detection as well as other health care applications (such as a reminder for drugs or blood sugar measuring) and are available for an integration in home environments (e.g., [17, 18]), hospitals [19], and nursing homes [20]. Different research projects focus on the development of holistic systems as well (e.g., [21, 22]) and some of these projects attach importance to integrate future users (in most cases older people) iteratively in the development process [23]. As the users' perspective is decisive for a successful integration of technologies in their everyday life, a user-centered design and development is necessary. Until now, smart home and especially AAL technologies are not systematically integrated in private home environments (in contrast to professional care contexts), although they have the potential to facilitate the everyday life of older, diseased, or disabled people. To understand the perception of smart home technology systems (and underlying usage motives and barriers), potential users and their perceptions, their mental models about aging as well as their wishes must be focused.

So far, smart home technologies have mostly been perceived and evaluated positive, while especially the necessity and usefulness of technical support have been highly acknowledged [22, 24]. Within these evaluations, the possibility of staying longer at the own home and an increased independency are relevant motives to use smart home and AAL systems. In contrast, the most relevant concerns and acceptance barriers deal with feelings of social isolation (e.g., [25]) and surveillance as well as invasion of privacy (e.g., [26]) if people were asked to think about a concrete integration of a system in their living environment.

To comprehend the trade-off between perceived benefits and barriers, analyses of technology acceptance and user diversity are needed considering not only traditional technology acceptance models (e.g., TAM and UTAUT) as they have been developed in completely different contexts and might thus not be applicable. In contrast to conventional ICT, smart home technology and AAL systems address especially older, diseased, and frail people with individual requirements, wishes, and concerns [27]. Hence, we assume that those specific user groups weight perceived benefits and barriers differently and show diverse acceptance patterns concerning assistive technologies and systems. In the following, an overview of acceptance research findings focusing on user diversity and different user group perspectives is presented.

To understand the elderly's perception of smart home and AAL technologies, numerous focus groups [28, 29] and interviews [24] with people (aged above 60 years) show similar recurrent results: perceived benefits in terms of staying longer at home, understanding the imminent lack of care staff, and the chances of AAL technologies contrast with concerns about dependency on technologies, the lack of personal contact as well as data security and privacy (e.g., [30]). Additionally, recent projects on smart home and AAL labs, e.g., Soprano [21], Philips Research Care Lab [31], eHealth Future Care Lab [32], have understood to integrate particularly older users into the design, development, and evaluation processes.

So far, previous research for smart home and AAL technologies has focused on elderly people with age-specific illnesses. In contrast, the acceptance of such technologies for disabled persons still needs more and specified research attention. While such assistive technologies could be specifically useful to support the inclusion of people with disabilities into society, to improve mobility and communication as well as to hold down a job, nearly any study so far investigated age and disability in depth. Some studies analyzed how diverse diseases and disabilities affect the use of assistive technologies (e.g., [33, 34]) and investigated why a high proportion of available technologies are rejected. Frequently, these analyses (focusing on technology acceptance of diseased or disabled people) remain on a theoretical basis and are in parts unspecific and superficial as they did not integrate disabled people. This is precisely where research is required:

disabled people have to be integrated in the design process of assistive technologies and the care-relevant user factors age, diseases, and disabilities should be focused.

To understand requirements and perceptions of disabled people in need of care, it is also important and useful to integrate and consider the perspectives of professional and family caregivers. So far, some studies [35, 36] have examined the requirements and professional and family caregivers' perspectives on AAL systems and technologies separately. Another study focused on future users (caregivers and patients) and their perceived concerns related to in-home monitoring technologies [37]. On the one hand, these studies enable first insights into diverse user perspectives on the acceptance of assistive smart home and AAL technologies. On the other hand, they do not allow a direct comparison of the perspectives of "affected people" (older, diseased, or disabled people) with family or professional caregivers compared to "not-experienced" people. Summarizing, there is sparse knowledge about the acceptance of smart home and AAL technologies regarding disabled people and people with special care needs as well as other care-relevant user factors. This is especially true for the perspectives of user groups with different experience and domain knowledge - disabled people, their relatives and family members as well as professional caregivers. For this reason, the current study focuses on the acceptance of assistive smart home technology systems with regard to people having different experiences with disabilities and resulting care needs.

3 Capturing Motives and Perceptions: Qualitative Insights

We choose a multi-method approach for our study consisting of a qualitative interview study and a consecutive quantitative questionnaire study. In this section, the research design is presented starting with a description of the qualitative interview study, which was taken as a basis for the subsequent quantitative study. Our approach addressed three essential research questions:

1. How do the participants evaluate a smart home technology system and which perceived benefits and barriers are most relevant for its acceptance?
2. To which extent does experience with disabilities influence the system's evaluation and the perception of benefits and barriers?
3. How are the relationships between perceived benefits, perceived barriers, trade-offs, acceptance, and experiences with disabilities (as user factor)?

As it was detailed in Sect. 2, previous research on the acceptance of AAL technologies was mostly focused on older users. In contrast, there is only sparse knowledge about developing AAL technologies for people with disabilities and also rarely research on the acceptance of AAL technologies focusing on users with different experiences regarding disabilities. Those diverse perspectives (e.g., professional caregivers, relatives and families of disabled people) are also of prime importance as they can support and complete the understanding of potential disabled user's needs and wishes. Hence, a qualitative interview study was initially necessary to identify perceived usage motives and barriers of usage. Only on this basis, it was reasonable to design and conduct a quantitative study focusing on people having different experiences with disabilities and resulting car needs (themselves, families and relatives, professional caregivers).

3.1 Methodology and Design

The methodology of guided interviews was chosen for the preceding qualitative study. Interviews in this sensible topic enable direct and personal contact to the participants, reach a more personal level, and ensure detailed discussions about personal topics. The interviews should provide insights into the desires, perceptions, and requirements of disabled people and people in need of care.

The interview guideline was structured in different parts. After introducing the topic and interview process, the participants were asked for demographic aspects as well as for personal information with regard to disabilities (e.g., own experiences; type, duration and symptoms of the disability). Afterwards, the participants were asked for some information concerning their living circumstances (i.e., housing situations, daily routine, incidental problems in everyday life).

Subsequently, a smart home technology scenario was read to the participants in order to show them a possible technical solution quite plainly that has the potential to facilitate their life. The scenario was used to create a basis for evaluation with regard to all interview participants and was designed as a very personal everyday situation. The participants should close their eyes while listen to the scenario and imagine that the scenario took place at their own living environment. Within the scenario, the implemented smart home technologies were not visible and enabled especially automatic lighting control (by light sensors and motion detectors), a hands-free kit for communication (by microphone, video-camera, and monitor), automatic control of doors and windows (by sensors and motion detectors), and memory functions (e.g., for drugs or measurement of medical parameters via smartphone).

Following the scenario, the participants were asked for their opinions on the described system as well as their ideas with regard to potential benefits and barriers. In the next part, the participants were explicitly consulted to indicate which motives and barriers were crucial for them and under which conditions they would use the smart home system. Specifically, the trade-off between increasing autonomy and independency on the one hand, and protecting own privacy and data security on the other hand has been focused. Finally, the participants had the opportunity to make previously not-mentioned, but for them personally important aspects a subject of discussion.

The guideline enabled that the conducted interviews were comparable, all relevant topics were mentioned and discussed, and all relevant questions were asked. Still, at any time, the participants could add questions, topics, and aspects, which were relevant from their point of view.

The interviews were recorded and protocols with relevant information (date, time, and place of interview, demographic information of participants) were prepared. Afterwards, the interviews were transcribed and anonymized. The interview's results were analyzed by qualitative content analysis [38].

3.2 Participants

As interview partners, we searched for participants who are disabled or in need of care themselves, relatives of disabled people in need of care, or professional caregivers of people with disabilities and care needs. The participants were recruited by personal contact and via email to reach associations and advice institutions regarding disabilities and care needs.

Nine participants (n = 9) were chosen and took part in the interviews that lasted between 40 and 70 min. Three participants were female (male: n = 6) and the participants were between 26 and 62 years old (M = 35.6). Seven interviewees indicated to have disabilities (n = 7) (e.g., infantile cerebral palsy, arthrogryposis multiplex congenita). Three disabled participants indicated to require support and assistance by an outpatient nursing service as well as support by a domestic help. Two participants made use of assisted living facilities, while in each case one participant lived in a stationary care institution and one participant needed currently no assistance in his everyday life.

Further, a relative of two disabled children (n = 1) and a professional caregiver (n = 1) took part in the study, who had both experiences with a broad range of disabilities.

3.3 Key Results

As the qualitative study served as a basis for the subsequent questionnaire study, the qualitative results were presented that are relevant for the subsequently presented quantitative results (i.e., perceived motives and barriers concerning the smart home technology system).

Potential Usage Motives. Eleven usage motives were identified during analysis. *Expansion of autonomy* represented an important motive for all participants as it is of great relevance for disabled people to are able to carry out everyday tasks autonomously. Closely related to this, the motive *to reduce dependency from others* was focused. Here, a participant (male, 32) took the example that he not wants to depend on others "keeping entrance doors open" for him as he perceives it as a kind of paternalism. Along with this, almost all disabled participants considered *compensation of mobility constraints* as important usage motive of a smart home technology system.

Facilitating everyday life was another important usage motive and the participants mentioned support for standing up and control of household appliances as examples. Most of the participants also focused on the motive *increase the feeling of safety* by using a smart home technology system, e.g., "…then you are able to look who is standing in front of your entrance door…" (female, 27). As further usage motive some participants mentioned *the relief of caring family, relatives and professional caregivers*: for example, disabled participants expressed that they don't want to ask their caregivers for minor details (e.g., "control of music" (male, 31)).

Two participants considered *time savings* as additional benefits by using a smart home system (e.g., tasks in household, automatic opening and closing of doors). One participant mentioned *comfort* as usage motive while it was not relevant for the other participants as they want to be supported only in the respective areas where they otherwise would need human assistance. Further, one participant mentioned that by using technologies the *confrontation with own care needs could be reduced*. *Staying longer at the own home* was mentioned as usage motive by the professional caregiver as he had the experience with some older people who could stay at their own home by means of using specific assistive technologies. Finally, the interviews illustrated that disabled people are in frequent contact with medical doctors and ministries: here, the exchange and access of data is very time-consuming as well as problematic and two participants assumed that an implemented system enables *a fast data access*.

Potential Usage Barriers. As one of the most relevant usage barriers *isolation due to the substitution of care staff by technologies* was mentioned especially by the relative and professional caregiver of disabled persons. In contrast, the disabled participants discussed this aspect controversially: e.g., "I would clearly prefer it if a robot would assist me on the toilet than care staff" (male, 33).

The usage barrier *feeling of surveillance* was discussed contrarily too: most of the participants criticized the feeling of surveillance and perceived the technology partly as an invasion in their own privacy, while a participant negated the feeling of surveillance and argued that "smartphones already collect lots of information" (male, 33).

As further potential usage barrier, some participants feared a *too large proportion of technology in their everyday life*. Along with this, it was crucial that the applied technology is functional and hence, *functional incapacity* of technologies and systems – not surprisingly – represented a central usage barriers. Accompanying, the applied system should be easy to operate and control; therefore, *the expectation of a too complicated handling* of the system also represented a usage barrier. Further, some participants mentioned concerns regarding transmission of false information, e.g., falls alarms.

Two participants mentioned a potential usage barrier if *more time is spent on technology usage compared to human assistance (no effective time savings)*. In almost all interviews it was mentioned that the system was perceived as useful if they are needed:

> "… as I can do most everyday tasks on own, I would currently decide against the system. However, I really like the opportunity to have it" (female, 37).

Along with this aspect, the interviews revealed that some people's *care needs are that intensive* that smart home technology are *not relevant and usefully applicable:*

> "The system does not substitute complete assistance – if I am not able to take a shower myself, then the system will not support me to do it" (female, 37).

The results concerning usage motives and barriers align with previous research concerning several aspects (e.g., comfort, facilitating everyday life (e.g., [39]). However, the results are multifaceted and go beyond previous findings due to the reference to disabilities and constraints (e.g., compensation, reduce confrontation with care needs, to be afraid of isolation). Hence, these aspects must be examined quantitatively to be able to do justice to diverse user groups and their different experiences with disabilities and care needs.

Perception of Assistive Smart Home Technologies. To get insights into the participants' perceptions and attitudes towards the described system, the participants were asked to describe their opinions using three associating words following the read scenario. Analyzing the used words, differences between the participants were striking: the relative and the caregiver predominantly used negative and critical words to describe their perceptions of the scenario such as *lonely, unhuman, heteronomous,* and *violation of personal rights and privacy*. In contrast, the disabled participants used more positive and fascinated words to describe their feelings and opinions. The most associated words were *exciting, facilitation, useful, helpful*, and *comfortable*. These results showed that a differentiation between the perspectives involved in caring situations is indispensable.

3.4 Conclusions for Quantitative Study

Within the individual interviews, we reached conversations on a very personal level with each interview partner and thus, spontaneous, individual and open answers were enabled. Regarding potential motives and usage barriers, 20 categories were defined and the participants' general attitude towards the introduced system was analyzed. The interviews gave an impression of how complex the issues "care" and "disabilities" are and how diverse the evaluation of assistive technologies can be if different user groups were considered. Even though the participants had different priorities in the interviews, we noticed, that all disabled participants expressed a distinctive wish towards independency and autonomy: it was very important for them not to become too conveniently and to be supported only in the respective areas where it is necessary. Most the participants emphasized the importance that disabled people or people in need of care should decide on their own if, and if so which technology is used.

The presented qualitative results served as a basis for the conception of the quantitative questionnaire. Additionally, the answers collected were used to create items regarding the trade-off between potential usage motives and barriers. Furthermore, the qualitative results confirmed that it is important and necessary to integrate people with different experiences concerning disabilities and needs for care and assistance into the follow-up quantitative study and future studies as well.

4 Quantifying Motives and Acceptance: Questionnaire Study

To quantify the previously gained qualitative results, an online questionnaire study was conducted focusing on people having different experiences with disabilities and care needs. Within this section, the methodological design, the sample, and the quantitative results are presented.

4.1 Methodological Questionnaire Design

Based on the findings of the previous interview study, we developed our online questionnaire consisting of different parts. The first part addressed demographic aspects, such as age, gender, educational level, and income. In the following part, the participants were asked for their experiences with disabilities by indicating (a) if themselves are disabled (b) if they are related to a disabled person, (c) if they are the caregiver of a disabled person, or (d) if they have no experiences with disabilities. Afterwards, the participants were asked to indicate, whether and to which extent (care time, type of care, intensity of care) themselves (a, d) or the person they put themselves in position with (b, c) needs care. As detailed attitudinal information, the participants evaluated several items concerning their needs for data security and privacy. Needs for data security were evaluated using 14 items (α = .87), while needs for privacy were assessed using eight items (α = .72).

A scenario was designed in order to ensure that all participants pertain to the same baseline regarding the evaluation of the smart home technology system. The scenario was conceptualized telling a very personal everyday situation wherein the participants should imagine that an specific, invisible smart home technology system was integrated in their home environment and contained the following functions: setting of the home temperature using the smartphone, automatic control of light control using light sensors and position localization, a hands-free kit for phoning enabled by integrated microphones, automatic opening and closing of (front) doors and windows via integrated sensors, monitoring of front door area by video camera, and fall detection by integrated sensors in floor and bed.

Depending on their background (need of care, experience with disabilities), the participants were introduced to the scenario differently. For cases b, c, and d, the participants were asked to put themselves in the/a disabled person's position (more specifically the person they are related with or they care (b + c)) while answering the questions concerning the smart home system scenario. Participants who indicated to be not in need of care were asked to imagine that they would need care during the scenario.

Afterwards, the participants evaluated perceived usage motives (11 items) of the system (e.g., to increase autonomy, to reduce dependency on others, to facilitate everyday life, to relieve fellow people) and perceived barriers of usage (9 items) (e.g., feeling of surveillance, no trust in functionality, to assume a too difficult usage, to be afraid of isolation) based on the findings of the qualitative interview study (see Sect. 3.2; all items are illustrated in Fig. 2). Additionally, the participants evaluated two trade-offs between perceived benefits and barriers: (a) autonomy and independency are more important than data security (three items; α = .84) and (b) data security and privacy are more important than the usage of smart home and AAL technologies (three items; α = .71). In the following part, the participants should assess the acceptance or rejection of the described system (by evaluating eight items, Fig. 1) including the behavioral intention to use such a smart home technology system. All items had to be answered on six-point Likert scales (1 = min: "I strongly disagree"; 6 = max: "I strongly agree").

Finally, the participants had the opportunity to reason their opinions towards the described system on an optional basis and to provide their feedback concerning the questionnaire and the topic itself. For completing the questionnaire, the participants took on average 15 min. Data was collected in an online survey in Germany (available for 6 weeks) in summer 2016.

4.2 Sample Description

182 participants volunteered to take part (acquired by personal contact and distributed online in social network forums). The participants were on average 38.7 years old (SD = 13.95; min = 20; max = 81), 62.1% of the sample were female, 36.3% were male, and 1.6% gave no answer asked for gender. Overall, the sample was highly educated with 46.7% holding an university degree and 14.8% an university entrance diploma.

Asked for their experience with disabilities, 28% of the participants indicated to be disabled (n = 51), 12.1% (n = 22) were professional caregivers, and 19.2% participants were relatives of a disabled person (n = 35). As a control group, we also integrated people without experiences regarding care and assistance needs caused by disabilities (40.7% (n = 74) of the participants were not-experienced). Concerning current needs of assistance and care, 43.4% (n = 79) participants indicated to need care or that the person - they put themselves in position with (see Sect. 4.1) - needed care (56.6% (n = 103) were not in need of care).

Correlation analysis revealed that the user factors were related only partially: not surprisingly, experience with disabilities correlated with current care needs ($r = .607$; $p = .000 < .05$). Age was not related with experience with disabilities ($r = -.132$; $p = .075 > .05$) nor with current care needs ($r = -.096$; $p = .197 > .05$). Instead, age was related with gender ($r = .200$; $p = .007 < .05$; 1 = female; 2 = male).

Further, the participants reported to have on average a positive technical self-efficacy (M = 4.5; SD = 1.0; min = 1; max = 6) and a slightly positive attitude towards technology innovations (M = 3.9; SD = 1.0; min = 1; max = 6). Additionally, they indicated their needs for data security (M = 4.1; SD = 0.8; min = 1; max = 6) and privacy (M = 4.4; SD = 0.7; min = 1; max = 6), which both were on average positive.

4.3 Detailed Group Description (Experience with Disabilities and Care Needs)

To understand the diversity of the user groups under study, their previous experiences, as well as their requirements and needs referring to care and assistance are presented in this section separately for each user group.

Disabled Participants (n = 51). Most of the participants with disabilities provided corresponding information about the type of their disability (n = 44): paralyses (in different extent) were mentioned very frequently (n = 17) (e.g., paraplegia, hemiplegia), followed by disabilities caused by muscle diseases (n = 9) (e.g., muscular atrophy, muscular dystrophy) and neurological diseases (n = 7) (e.g., multiple sclerosis, Parkinson's disease). Further, disabilities in terms of missing extremities (i.e. legs) (n = 2) and other walking impediments (n = 9) (e.g., dwarfism, contracture) were mentioned. Nearly half of the participants reported to be disabled by birth (47.1%), the other participants reported to suffer from their disability a long time ago (in years: M = 25.3; SD = 18.3; min = 3; max = 64). Two thirds of the participants reported to be constantly in need of care (66.7%, n = 34). Most of them indicated to be assisted by their families/partners in combination with professional care staff (n = 15) or only by families/partners (n = 12), whereas few participants were assisted only by professional care staff (n = 3). N = 23 participants reported to need assistance in the areas body care, mobility, housekeeping, and nutrition, while only two participants needed assistance in two of these areas (n = 9 in three areas).

Relatives of Disabled People (n = 35). Asked for the living circumstances of their disabled relative, the majority (67.6%) reported that he/she lived together with the family, while each 8.1% live alone, with partner, or in a flat-sharing community. More than half (54.3%) of the participants indicated that their relatives are disabled by birth.

82.9% of the participants (n = 29) reported that their relatives are constantly in need of care, while the daily time for care was on average 7.4 h (SD = 6.8; min = 1; max = 24). The majority of the disabled relatives in need of care is cared by their families and partners (n = 15) or by professional care staff and their families/partners (n = 11). In contrast, few participants were cared only by care staff (n = 3). Further, most of the disabled relatives in need of care (n = 19) needed assistance in the following four areas: body care, mobility, housekeeping, and nutrition. All of them (n = 29) needed assistance in at least two of the mentioned areas.

Professional Caregivers (n = 22). Asked for the living circumstances of the people the professional caregiver group maintained, they reported that 40.9% live in stationary care facilities, 27.3% live with their family, 13.6% live alone, and each 9.1% in a flat-sharing community and in assisted living. Further, they indicated that the majority (81.8%) was constantly in need of care. In contrast to the group of disabled participants who indicated to be physically disabled, the professional caregivers maintained people with physical and mental disabilities (e.g., trisomy 21, autism). Almost all of these people needed assistance in the areas body care, mobility, housekeeping, and nutrition.

Participants with No Personal Experience Regarding Disabilities (n = 71). 43.2% indicated to live together with their partner, 24.3% live together with their family, 17.6% live alone, and 14.9% live in a flat-sharing community. Not surprisingly, none of the not-experienced participants indicated to need care.

4.4 Key Results

First, the results were analyzed descriptively, followed by linear regression analyses and by (M)ANOVA procedures to investigate potential effects of user diversity (level of significance was set at 5%). Independent variable was the experience with disabilities to analyze the influence of assistance and care needs on perceived benefits, barriers, and acceptance as dependent variable. The results section starts with the description of the findings for acceptance of AAL, perceived benefits, and perceived barriers referring to the whole sample. Then, influences of user-specific characteristics on perceived benefits and barriers as well as acceptance of smart home technologies are reported [40]. Finally, the relationships between the perception of benefits and barriers and smart home technology acceptance are focused, modelled, and complemented by effects of user diversity.

General Acceptance of AAL. Aprior study [40] focused on acceptance of smart home and AAL technologies, which was on average positively evaluated (M = 4.6; SD = 1.0).

Zooming into the evaluation of the respective items (Fig. 1), the participants' highest agreement was found for items referring to care needs (*...due to care needs* (M = 4.7; SD = 1.1) and ... *reduce my care needs* (M = 4.5; SD = 1.3)). In comparison, items with regard to the intention to use an AAL system were rated less positive (e.g., *I can imagine using AAL technologies now* (M = 3.8; SD = 1.6)). The participants rejected all items that militate against usage similarly (e.g., *I think AAL technologies are superfluous* (M = 1.9; SD = 1.1)).

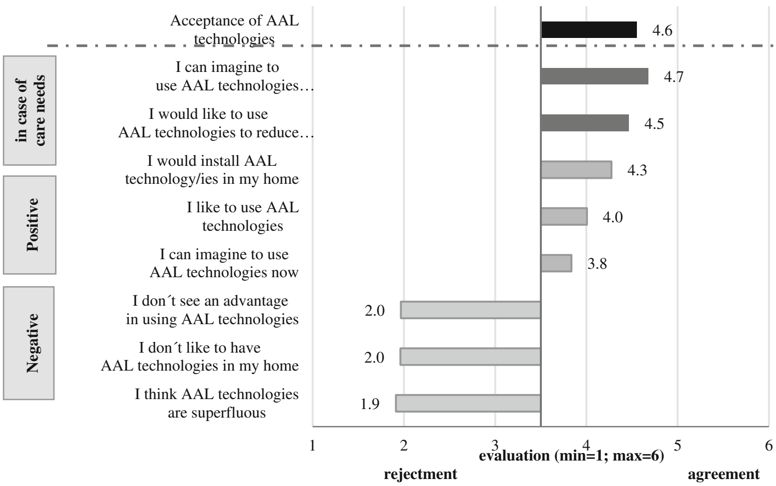

Fig. 1. Evaluation of AAL system acceptance [40].

Figure 2 (left) shows the results of the evaluation of perceived benefits of the AAL system. Apparently, all items were perceived as benefits (above the scale's mean).

The benefit *to facilitate everyday life* (M = 5.2; SD = 0.9) was evaluated highest, followed by *to expand own autonomy* (M = 5.2; SD = 1.0), *to extend staying at home* (M = 5.1; SD = 1.0), and *to reduce dependency from other people* (M = 5.1; SD = 1.0). The items *to relieve fellow people* (M = 4.9; SD = 1.1), *to compensate reduced mobility* (M = 4.8; SD = 1.0), *comfort* (M = 4.7; SD = 1.2), and *to increase the feeling of safety* (M = 4.6; SD = 1.3) were lesser important. *Time savings* (M = 4.3; SD = 1.4), *to enable fast data access* (M = 4.0; SD = 1.4), and *to reduce own conflict with care needs* (M = 3.9; SD = 1.4) were comparably minor important.

To understand which items are most relevant for the decision to use AAL systems, we conducted a stepwise linear regression analysis with all perceived benefit items as independent and the acceptance sum score as dependent variable. The results revealed two significant models for the whole sample. The first model predicted 27.2% (adj. $r^2 = .272$) variance of acceptance and was premised on the benefit *to expand own autonomy* ($\beta = 0.525$; $t = 8.279$; $p < .000$). Hence, *to expand own autonomy* was the most important benefit for the acceptance. The second model explained 29.2% (adj. $r^2 = .292$). Beyond the already identified factors, additionally the item *time savings* was included. Therefore, *time savings* ($\beta = 0.166$; $t = 2.459$; $p < .05$) and *to expand the autonomy* ($\beta = 0.462$; $t = 6.823$; $p < .000$) were the most important benefits and influenced the acceptance of the described system.

Figure 2 (right) illustrates the evaluation of perceived barriers of the system. In contrast to the perceived benefits, none of the items was perceived as "real" barrier - as all values were below the mean of the scale. Zooming into the items' evaluation, the participants perceived the system not as *superfluous* (M = 1.9; SD = 1.0) or *irrelevant* (M = 2.4; SD = 1.1). They judged the *usage not to be too difficult* (M = 2.6; SD = 1.2) and rejected *to have no trust in the functionality* (M = 2.8; SD = 1.3). The items

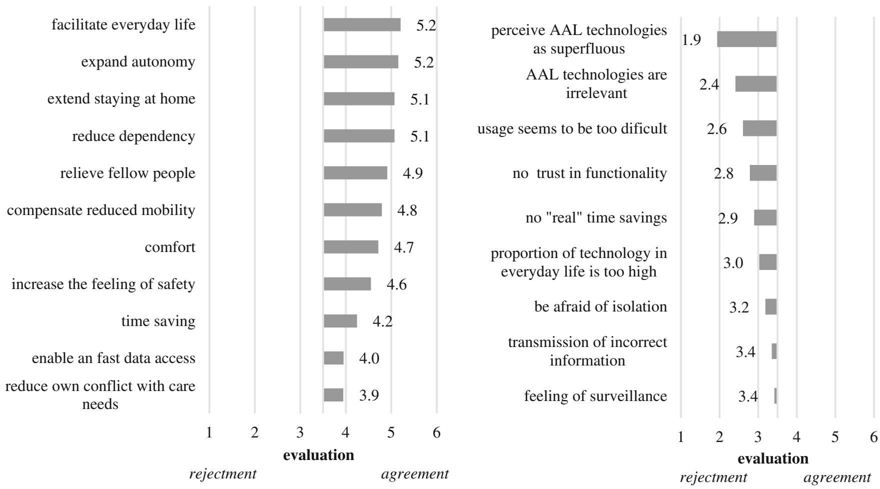

Fig. 2. Evaluation of perceived BENEFITS (left) and BARRIERS (right) regarding the described AAL system scenario [40].

proportion of technology in everyday life is too high (M = 3.0; SD = 1.5) and *to expect to have no "real" time savings* (M = 2.9; SD = 1.2) were slightly rejected by the participants. This was also true for the item *to be afraid of isolation* (M = 3.2; SD = 1.5). In comparison, *transmission of incorrect information* (M = 3.4; SD = 1.3) and *feeling of surveillance* (M = 3.4; SD = 1.5) were rated rather neutrally, thus, these two items were the most likely barriers.

After descriptive analyses, a stepwise linear regression analysis was also conducted in order to figure out which barriers influenced the acceptance of the system the most. For this purpose, perceived barriers were integrated as independent and the acceptance sum score as dependent variable into the analysis. The results revealed three significant models for the whole sample. The first model predicted 35.1% acceptance variance (adj. r^2 = .351) premised on the barrier *AAL technologies are irrelevant* (β = −0.596; t = −9.945; p < .000). Apparently, participants accept the AAL system only if it is really needed and that they want to do as much as possible autonomously on their own. The second model explained 41.7% (adj. r^2 = .417) and contained additionally the barrier *proportion of technology in everyday life is too high* (β = −0.285; t = −4.624; p < .000) (*irrelevant* (β = −0.484; t = −7.850; p < .000)). Ultimately, the final model explained 42.9% (adj. r^2 = .429) and was premised on the factors *to be afraid of isolation* (β = −.139; t = −2.151; p < .000), *proportion of technology in everyday life is too high* (β = −0.235; t = −3.591; p < .000), and *AAL technologies are irrelevant* (β = −0.453; t = −7.228; p < .000). As the analyses of acceptance, benefits, and barriers regarded the whole group so far, it was of importance to investigate whether these factors differ even more regarding diverse user groups. Additionally, it was important to analyze whether and to which extent the system's acceptance differed depending on users with different needs for assistance and care.

User-Specific Characteristics. For this analysis, the factor experiences with disabilities was integrated as independent variable to analyze the influence of living with disabilities on the acceptance, perception and evaluation of AAL systems.

User-Specific Acceptance of AAL Systems. The MANOVA analyses showed a significant influence of experiences with disabilities ($F(24,465) = 2.060$; $p < .01$) on the acceptance of the described smart home system. This influence occurred for all respective items and is illustrated in Fig. 3.

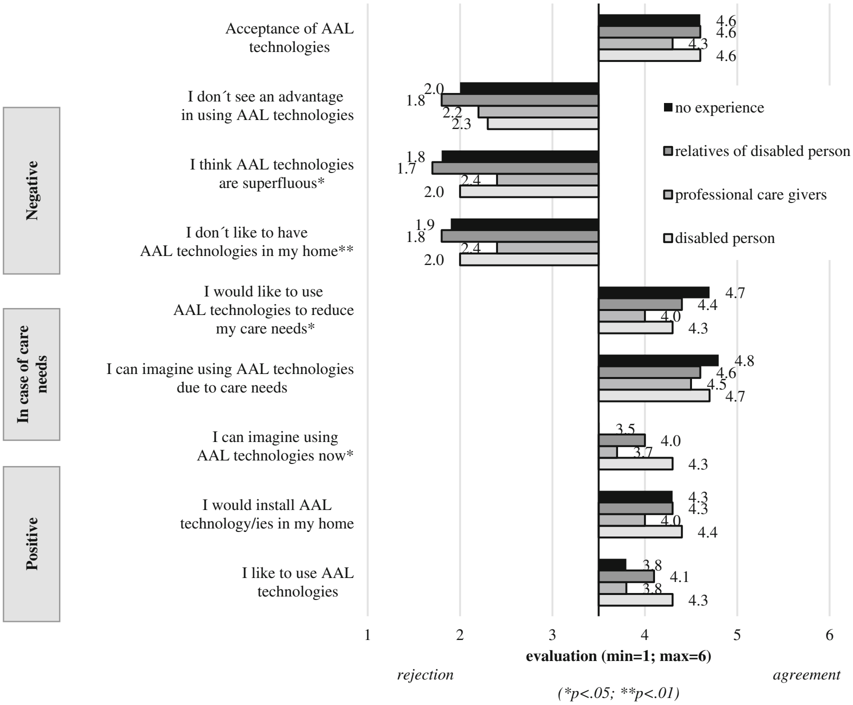

Fig. 3. Evaluation of acceptance depending on the user factor experience with disabilities [40].

The sum-score *acceptance of AAL technologies* was rated rather similar, except for the professional caregivers who showed comparatively the lowest acceptance scores ($F(3,162) = 2.646$; $p < .1$). With regard to two of the negative statements (…*superfluous* $F(3,162) = 2.895$; $p < .05$) and … *don't like to have AAL technologies in the own home* $F(3,162) = 4.907$; $p < .01$), the professional caregivers showed the lowest rejection. This showed, that they in tendency possessed a higher negative attitude towards the described system than the other three user groups. This evaluation picture occurred again for the item *the intention to use AAL technologies to reduce care needs* ($F(3,162) = 2.981$; $p < .05$): the disabled participants, relatives of disabled people, and not-experienced participants showed a clearly higher agreement, while the professional caregivers showed the lowest acceptance scores. Interestingly, the group of not-experienced participants showed the highest agreement referring to the two *"in case of care needs*"-statements. This evaluation pattern changed regarding the more concrete intention to use item *I can imagine using AAL technologies now*, which was clearly lower agreed by the not-experienced participants (M = 3.5; SD = 1.7) compared to the group of disabled people (M = 4.3; SD = 1.3; $p < .05$, post-hoc-tests: Tukey's HSD).

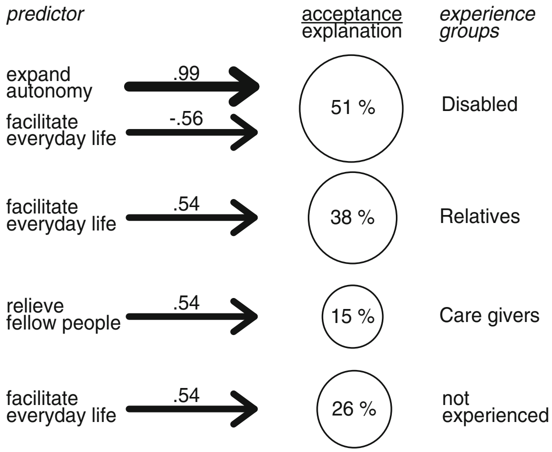

Fig. 4. Results of regression analysis – benefits & acceptance for experience with disabilities groups [40].

User-Specific Evaluation of AAL Benefits. MANOVA analyses revealed no significant omnibus effect of experiences with disabilities on the evaluation of benefits. In contrast, some of the single benefit items were rated significantly different depending on the user factor experience with disabilities. In a next step, we conducted a stepwise linear regression analysis to investigate which benefits are most important and acceptance-relevant for which user group and acceptance-relevant for which user group. The results of the regression analysis referring to the experience with disabilities user groups are illustrated in Fig. 4.

The final regression model for the group of disabled participants predicted 50.5% (adj. $r^2 = .505$) of the system's acceptance and was based on the benefits *to expand autonomy* ($\beta = .985$) and *to facilitate everyday life* ($\beta = -.564$). For the group of relatives of disabled people the model explained 37.5% of variance (adj. $r^2 = .375$; $\beta = .535$) and for the not experienced group 25.5% (adj. $r^2 = .255$; $\beta = .633$) - in each case based on the benefit *to facilitate everyday life*. For the professional caregivers, the final regression model explained only 15.4% (adj. $r^2 = .154$) of acceptance variance and was premised by the benefit *to relieve fellow people* ($\beta = .399$).

User-Specific Evaluation of AAL Barriers. The same procedure was conducted for the perceived barriers as previous MANOVA analyses revealed only a slight significant omnibus effect of experiences with diseases ($F(27,468) = 1.502$; $p < .1$) and again single barriers were rated significantly different. The results of the final linear regression analyses for all experiences with disabilities groups are illustrated in Fig. 5.

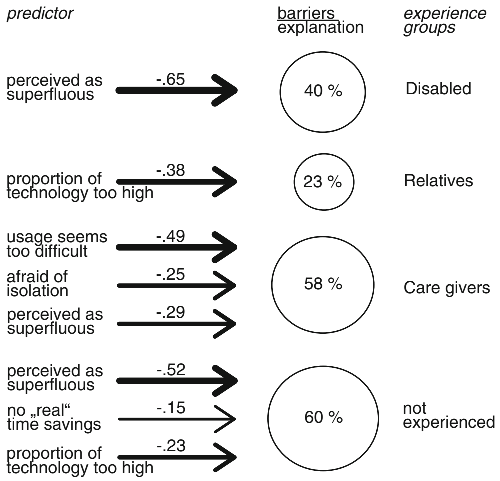

Fig. 5. Results of regression analysis – barriers & acceptance for experience with disabilities groups [40].

For the groups of relatives, the model predicted only 23.1% of variance of acceptance (adj. $r^2 = .231$) and with the barrier *the proportion of technology in everyday life is too high* ($\beta = -.376$). For the group of disabled participants, the model explained 39.9% of AAL acceptance variance (adj. $r^2 = .399$) premised on the barrier *to perceive AAL technologies as superfluous* ($\beta = -.649$). With regard to the group of professional caregivers, the final model predicted 58.3% (adj. $r^2 = .583$) of variance and was affected by the barriers) *to perceive AAL technologies as superfluous* ($\beta = -.293$), *usage seems to be too difficult* ($\beta = -.494$), and *to be afraid of isolation* ($\beta = -.249$). Finally, and referring to the not-experienced group, the final model explained 60.2% of AAL acceptance variance based on the three barriers *to expect no "real" time savings* ($\beta = -.154$), *to perceive AAL technologies as superfluous* ($\beta = -.520$), and the concerns that *the proportion of technology in everyday life is too high* ($\beta = -.227$).

4.5 Acceptance Model Relationships

In order to figure out how perceived benefits, barriers, and trade-offs between them are related with the acceptance of smart home technology systems, correlation analyses were calculated (see Fig. 6). The results showed that *perceived benefits* ($r = .497$; $p < .01$) and *perceived barriers* ($r = -590$; $p < .01$) were directly related with the acceptance of the described system. Further, the integrated constructs dealing with trade-offs between benefits and barriers were both related with acceptance: the tradeoff that *autonomy and independency as benefits are more important than data security*

(TO1) was related with acceptance (r = .438; p < .01) and - not surprisingly - with perceived benefits (r = .486; p < .01). Further, the trade-off that *data security and privacy are more important than the usage of smart home and AAL technology systems (TO2)* was negatively related with acceptance (r = −.374) and – also not surprisingly – with perceived benefits (r = .471; p < .01).

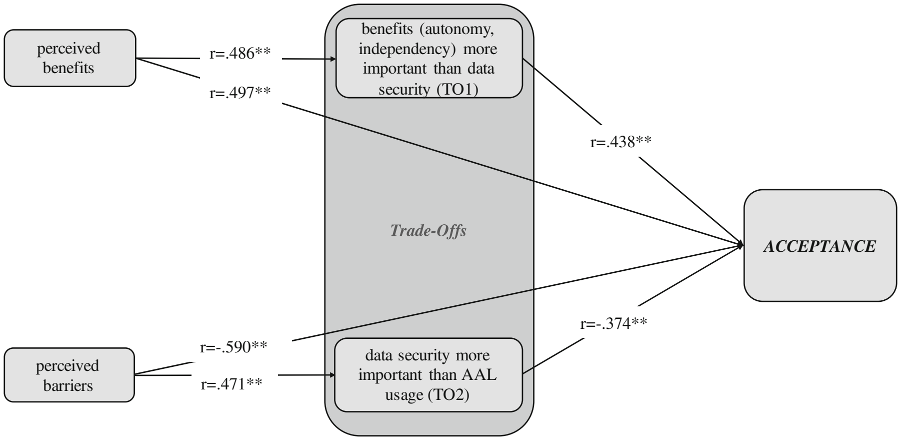

Fig. 6. Model of relationships between perceived benefits, perceived barriers, and AAL acceptance.

In a second step, we also included user diversity as well as attitudinal variables into the analysis. Figure 7 illustrates the relationships between perceived benefits, barriers, their trade-offs, and acceptance including user and attitudinal factors.

The grey arrows show that the attitudinal variables *need for privacy* and *need for safety* were significantly related with the previously described acceptance model. Correlation analyses revealed that the needs for data security were related with the perception of barriers (r = .344; p < .01), however only marginally with the perception of benefits (r = −.160; p < .1). Further, needs for data security were linked to both tradeoffs TO1 (r = −.435; p < .01) and TO2 (r = .488; p < .01) as well as to acceptance (r = .−310; p < .01). Similarly, needs for privacy were related to perceived barriers (r = .238; p < .01) as well as tradeoffs TO1 (r = −.339; p < .01) and TO2 (r = .460; p < .01).

The black arrows illustrate the influence of experience with disabilities within the acceptance model. This factor significantly influenced the perception of barriers (not the perception of benefits) as well as the acceptance of the described system. Interestingly, experience with disabilities was also linked to the evaluation of trade-offs *autonomy and independency as benefits are more important than data security (TO1)* (F(3,178) = 2.995; p < .05) and *data security and privacy are more important than the usage of smart home and AAL technology systems (TO2)* (F(3,178) = 3.968).

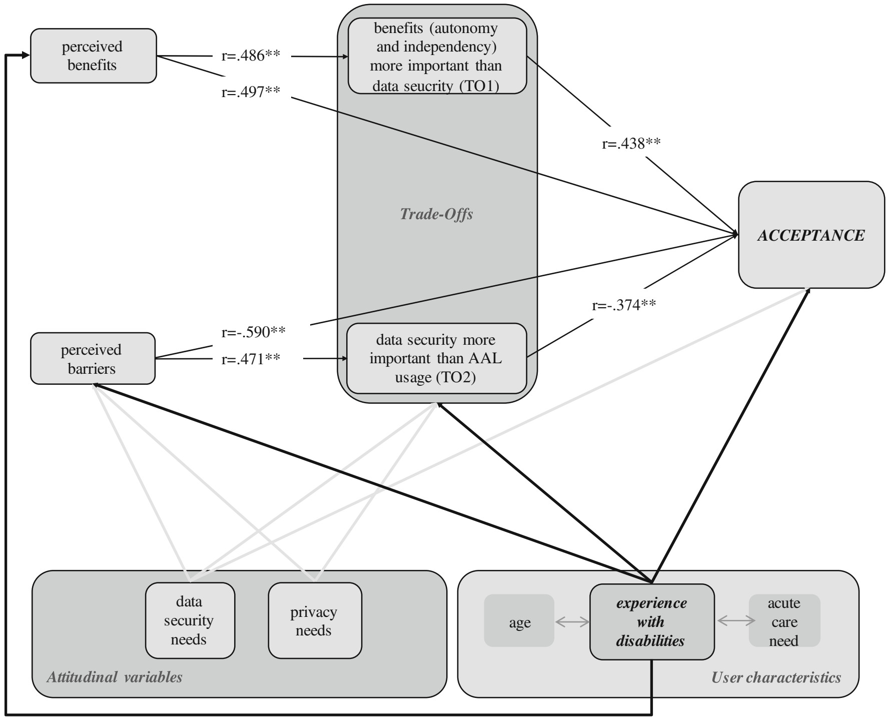

Fig. 7. Model of relationships between benefits, barriers, and acceptance complemented by the influence of user diversity factors.

5 Discussion

Sections 5.1, 5.2, and 5.3 provide discussions of the previously presented research results as well as answers to the study's underlying research questions (see Sect. 3.1). Further, limitations and an outlook for future research in the field are presented (Sect. 5.4).

5.1 Decisive Perceived Benefits and Barriers for Smart Home Acceptance

In accordance with previous research results [22], our results show that a holistic smart home and AAL system with a wide spectrum of functions is overall accepted and rated positive by all user groups. Referring to the context of care needs, the intention to use the system is present and differs only slightly regarding the different user groups. Whenever potential care needs are subject of discussion in an intention-to-use-context, they are more important than other wishes or concerns and the AAL system would be used in this regard.

Overall and referring to the whole participant group, the acceptance was more predicted and explained by perceived barriers than by perceived benefits. The results of the regression analyses for all participants reveal that *expanding the autonomy* was the beneficial factor with the biggest influence on acceptance followed by *time savings*. Concerning perceived barriers, *to be afraid of isolation*, *proportion of technology in everyday life is too high*, and *AAL technologies are irrelevant* were the most acceptance-relevant criteria. In parts, these results are in line with previous research [39, 41], in which especially older participants were afraid of the proportion of technology and a potential isolation in consequence of technology usage. As mentioned before, these new results in the context of experience with disabilities and resulting care needs should be addressed and deepened in future studies. Interestingly, the evaluation of perceived benefits and barriers as influencing factors for the acceptance of smart home systems strongly depends on experience with disabilities and care (see Sect. 5.2).

5.2 The Perspective of Experience with Disabilities

Although the system was overall accepted and evaluated positive by all user groups (see Sects. 4.4 and 5.1), some significant differences between the groups are striking and are illuminated in this section.

If it was asked for the intention to use the system without mentioning the context of care needs, significant differences between the user groups become obvious: in tendency - disabled people and people in need of care indicate a clearly higher acceptance (intention to like to use an AAL system currently or to install an AAL system in their home environment) compared to healthy people without personal experiences with disabilities or care needs. Thus, the fact that people are concerned with health issues and care needs influences the AAL system acceptance. This is a common research finding regarding age as previous research revealed that older participants show higher acceptance scores of assisting technologies than younger people [41]. However, this is a comparatively new phenomenon concerning diseases and disabilities. Focusing on different experiences with disabilities, the evaluations of the professional caregivers group are striking as they indicated to have a more negative attitude towards AAL systems in comparison with all other groups [42]. Particularly, this was obvious during the statements in the interview studies, in which the professional caregivers described AAL systems in parts as spooky, impersonal, or inhuman. Due to previous research findings and current studies, we assume that professional care staff takes a more critical attitude than other user groups due to concerns about a difficult handling of the technology, concerns to be replaced by technology, and also due to a lower general trust in technology. Hence, future studies should focus especially on professional caregivers and analyze their requirements and wishes to be able to integrate them into the development of smart home and AAL technologies and finally, to increase their openness and acceptance of such technologies in professional care contexts.

The evaluation of motives to use and perceived barriers not to use an AAL system differed also regarding user diversity. As a first aspect, it is striking for the group of disabled participants, that the main perceived benefits carry greater weight than the perceived barriers (see Sect. 4.4). The disabled participants of our study associate the in the scenario described AAL system as helpful, very useful, and comfortable. It is most important for them that the applied technical system helps to *expand their autonomy*. In contrast, *facilitation of everyday life* is a comparatively incidental or even not desired benefit as most people of this group want to cope with as much everyday tasks as possible on their own. Hence, smart home and AAL technology systems could be very enriching for disabled people as they have the potential to help those people to help themselves. In contrast, the most important barrier for this participant group represents the aspect that the use of technology is *seen as superfluous.* As this refers to the concern that the technology undertakes tasks the people would like to do autonomously, it represents the most important benefit's counterpart and highlights the importance of autonomy for this specific user group.

Referring to the perspective of relatives of disabled people, their acceptance results can be best compared with the disabled people's perspective: for them, also the perceived benefits are in tendency more important than the perceived barriers. However, this is not true for the most important usage motives: in line with previous results [39] (but in contrast to the results of the disabled participants group), for the not experienced group, the relatives, and the professional caregivers groups, the benefits *facilitation of everyday life* and *relief of fellow people* are the key motives to use AAL systems.

Focusing the not experienced and the professional caregivers group, the perceived barriers carry clearly more weight than the perceived benefits of smart home and AAL systems. This fits the results of the qualitative study, in which the professional caregivers described the system primarily as spooky and undesirable (see Sect. 3.3). However, there are also differences between these two groups as they weight the perceived barriers differently. For the professional caregiver group, concerns about a difficult usage of the technology is relevant. We assume that this is due to concerns that the workflow is affected and slowed down by technical and especially handling difficulties. In contrast, doubts about a too high proportion of technology and if the technology is really necessary are relevant barriers for the not-experienced group.

Summarizing, this study's results show that the acceptance of smart home and AAL systems depends on the user factor experience with disabilities and resulting care needs. Besides acceptance, the motives for use or non-use of the described system differ with respect to user diversity. Based on the presented results, we suggest including disabled people into early development stages of smart home and AAL technologies to reach technical solutions that are personalized and sufficiently adapted to individual requirements. Equally, professional care staff should be integrated in future studies as they present the most critical users. Thus, not only facilitating and management of everyday life can be ensured at home but also at professional care environments and contexts.

5.3 A Holistic View: Relationships Between Benefits, Barriers, and Trade-Offs

Although the presented model shows that perceived barriers influence the acceptance more strongly than perceived barriers, the direct trade-offs between them are predominantly evaluated in favor of the benefits and system usage. The weightings and trade-offs between perceived benefits and perceived barriers clarify the importance to conceptualize respective communication and information strategies thoroughly. By providing easily comprehensible information about the usage of the system, the data handling, technical characteristics as well as the potential applications of the system, concerns and fears could at least be reduced.

The model as well as Sect. 5.2 also illustrate that user diversity clearly shapes smart home and AAL system acceptance. Besides experience with disabilities, especially needs for privacy and data security present factors that are extremely relevant for acceptance as well as for the perception of benefits and barriers within the present study. This is detailed in another study [43] and in line with numerous previous investigations in the field of AAL and smart home acceptance research [26, 39], wherein data security and privacy mostly present perceived barriers and thus, acceptance-relevant criteria.

5.4 Limitations and Future Research

Although the presented two-step empirical study revealed insights into the acceptance of smart home and AAL systems considering users with different experiences concerning disabilities, some limitations concerning methodological approach and sample should be considered for future research in this field.

Initially, the study was a first approach comparing users with different experiences in the context of care and disabilities; therefore, we concentrated on the evaluation of crucial benefits and barriers as well as on the acceptance of our described system in general enabling smart home (e.g., heating, lighting) as well Ambient Assisted Living functionalities (e.g., remembering, monitoring). In future studies, we will be able to integrate more detailed aspects, e.g., relationship between privacy and safety, detailed data security evaluation (period and kind of data storage, data access), that have not been considered so far. Second, the study focused on a holistic multi-functional and its evaluation and not on an evaluation of single technologies and functions as they have already been largely researched. It would be very interesting to analyze if scenarios with slightly divergent descriptions (e.g., adding or changing functions) of a holistic AAL system will be evaluated differently. Of course, the scenario-based approach of our study must be noticed: the evaluation based on a fictional and not on a real AAL system and therefore, we will conduct an evaluation of the real system and will compare the scenario-based and real evaluations as soon as the system is ready to be integrated in care institutions as well as private home environments.

Further, there are also some aspects concerning the sample which should be considered for future studies. The study's sample size was adequate, but the study should be replicated in even larger and especially more representative samples: this was especially true for gender because the sample contained a higher number of women than men. In our sample, age was not related to disabilities or current care needs and therefore our study reached younger as well as older people with disabilities. Nevertheless, it is desirable to try to reach a higher proportion of "old and disabled" people in order to be able to focus on the new phenomenon of "old" disabled people [8] and on the requirements and wishes of these people. A last cultural aspect refers to the fact that the present study addressed German participants and represents a single country perspective with a country-specific health care system. Thus, a comparison of smart home and AAL technology acceptance depending on different countries and their specific characteristics would be desirable to compare future user needs culture-specifically.

6 Conclusion

Addressing the increasing challenge to tackle demographic change and care of elderly and disabled persons, the development of smart home and AAL technologies is a promising approach. The acceptance of users and the broad willingness to use these technologies at home represent the critical cornerstone for a sustainable adoption of those technologies. While research increasingly provides differentiated insights into acceptance research in the context of age and generation, so far, sparse knowledge is prevailing about the acceptance of disabled persons and resulting care needs.

The current study therefore concentrated on the perspective of persons having different experiences with disabilities and care needs. A two-tier approach was pursued: First, a qualitative interview was conducted to gain insights into opinions, wishes, and needs of disabled persons. In addition to the affected persons themselves, we also included relatives of disabled persons, professional caregivers, and, as a control group, persons without experience with disabilities. Second, a questionnaire study was carried out, in which we explored perceived benefits and barriers, use conditions, and acceptance of AAL technologies.

The results showed that acceptance as well as perception of benefits and barriers regarding AAL and smart home technologies depend on user diversity and particularly usage motives and barriers are pronounced and weighted differently referring to user groups having different experiences with disabilities and care needs.

The presented study enabled an identification of user-specific benefits and barriers of smart home and AAL technologies as well as building an acceptance model containing perceived benefits, perceived barriers, their trade-offs, system acceptance and the influence of user diversity factors. Thus, the current study contributes to a deeper understanding of user-specific AAL and smart home technology acceptance focusing on disabilities and care needs. A premature and iterative integration of users with different experiences and needs in the development process of assistive technologies is not merely desirable but also necessary to increase user acceptance and adoption in the context of innovative AAL and smart home technologies.

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Home-Based Multi-parameter Analysis for Early Risk Detection and Management of a Chronic Disease

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Abstract. Proactive support of patients with chronic diseases such as Congestive Heart Failure is vital since the recovery from a critical condition usually presents complications and it is not always possible. Although emergency situations may occur without prior warning, still in the majority of emergency cases, there are "signals" that precede their appearance. By capitalizing on technology developments that are changing the way how healthcare services are provided, we propose a multi-parameter and multi-level data analysis approach in order to detect possible alarms which can then trigger proper preventive medical interventions. The main contribution of the presented approach is a methodology that combines selected health parameters that can be measured in a home environment using ambient assisted living technologies, with clinical history, in order to design a risk detection system for a chronic disease based on a Bayesian reasoning network. The added value of the proposed approach is that the system not only collects, processes and transmits vital measurements to the healthcare experts but also detects risks within the collected data. The system developed is discussed in detail as well as the validation process performed both on a technical and a medical level.

Keywords: Risk prevention · Bayesian network · Chronic diseases
Medical knowledge modelling · Remote healthcare · Multi-layered architecture
Sensors · Pervasive computing · Ambient assisted living

1 Introduction

World population aging is accompanied by a significant increase of chronic diseases, such as Congestive Heart Failure (CHF) and Diabetes Mellitus (DM). The cost of managing chronic diseases is huge representing 48% of global GDP (Gross Domestic Product) in 2010 and estimated to approach at a global level 30 trillion US$ in the next two decades [1]. At a national level, treatment expenses can be high and the loss of labor due to chronic diseases can make a substantial dent in a country's productive

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capacity. Additionally heavy burdens are put in the care system for the management of patients devoting resources directly or indirectly to prevention, screening, treatment and care. These difficulties render the management of such medical problems at home as an extremely attractive solution.

However, the management and treatment of chronic diseases at home presents many challenges for patients, their caregivers and health professionals, particularly with respect to the prevention and treatment of dangerous situations and complications such as deregulation-hospitalization in patients with CHF or hypoglycemia in patients with DM. Telemedicine monitoring of patients with chronic conditions has been proposed as an alternative for patient monitoring and early risk detection, however the plethora of parameters that accompany their remote monitoring, create challenges in the management of telemedicine services [2].

The development of information and communications technology systems that integrate modeling of medical knowledge and using of advanced processing techniques on medical and other data can assist the physicians in a diagnostic level, and contribute effectively to the prevention of health risks for the patients. In this perspective we present here the development of a home-based system for supporting CHF patients and addressing the early detection and management of health risks. At the heart of the system lies a multi-parameter analysis process for the early detection of critical medical conditions in CHF patients using artificial intelligence methods for modeling the medical knowledge and algorithmic data processing techniques to extract diagnostic features.

The main contribution of our approach is a methodology that combines health measurements that can be taken in a home environment using ambient assisted living technologies, with clinical history, in order to design a risk detection system for CHF that uses a Bayesian reasoning network. The added value of the proposed approach is that the system not only collects, processes and transmits vital measurements to the healthcare experts but also detects CHF risks within the collected data.

The rest of the text is structured as follows. In Sect. 2 we elaborate on the Bayesian Network model we have used to represent the domain knowledge and build a probabilistic reasoning method. Furthermore, related work is discussed and compared to our approach. Section 3 introduces the multi-parameter and multi-level data analysis approach that is followed in order to detect possible alarms which can then trigger proper preventive medical interventions. In Sect. 4 we discuss details of system development in terms of the logical layers found at the endpoints of the client-server architecture followed and the tools used for measurement scenario management and for system implementation. Section 5 gives information on the validation process performed both on a technical and a medical level. Finally, Sect. 6 gives our conclusions and suggestions for future work.

2 Background

In the domain of disease diagnosis many approaches have been proposed using Artificial Intelligence techniques, however, because on the one hand the expert knowledge in the medical domain is very important and on the other hand the experts want to clearly distinguish the way a diagnostic algorithm reaches a conclusion, Bayesian

Networks (BNs) and in particular a variation for continuous data, called dynamic BNs, have been popular and at the same time a powerful approach [3, 4].

A BN is a graphical model, in particular a directed acyclic graph (DAG), which can express probabilistic relationships among a set of nodes or variables whereas arcs represent causal relations among the variables [5]. BNs have been used, for example, to model domain knowledge with a perception of causal effects for asthma case finding [6], for pneumonia [7], for hyper-kinetic disorder [8] and for early detection of hyperglycemia in patients with diabetes [9]. BN-based diagnostic systems for heart failure have been also developed [10] while the typical approach for BN construction is the use of clinical data [11].

BN model construction requires the specification of Conditional Probability Tables (CPTs) which denote the statistical dependence of the corresponding variables. However, for a specific variable, the number of parameters in the CPT is exponential to the number of parent nodes in the BN and thus can be prohibitive for the BN building. An approximation that considers a causal independence among the parent nodes that model causes related to the child node that model the effect can significantly reduce the dimensions of a CPT. This assumption is known as the Noisy-OR model [12] giving a logarithmic complexity on the number of parameters required for the CPT.

A critical question that arises when using the Noisy-OR model to build a BN is whether the performance of the network's reasoning is affected. There have been many studies that examined the effects of using this approximation for specifying the CPTs of a BN. For heart failure diagnosis the Noisy-OR model was successfully used to alleviate the difficulties involved in providing statistical data for all possible combinations of predecessor variables that, all or some combination of them, may cause heart disease [11]. For asthma case finding, an empirical study compared the original BN which was constructed from clinical data taken from a large medical database, with a BN that constructed using the leaky Noisy-OR formalism [6]. Comparison of the two methods concluded that the causes of asthma are independent and therefore both BNs had similar results, proving that the Noisy-OR approach is a strong assumption and a valid construction method for Bayesian reasoning networks. In a similar comparative study related to the early detection of classical swine fever original probabilities of the BN were replaced by Noisy-OR calculated probabilities with the involvement of the domain expert without affecting the sensitivity of the reasoning network [13]. The consistency of the outcomes reported by the above and similar studies led us also to use the Noisy-OR model in our approach for the early detection of CHF risks.

Focusing on heart failure risk detection many approaches have been proposed. An example is an early warning system for CHF using a BN which combined weight and blood pressure data with the location of the user and context-specific health questions in order to calculate a risk probability [14]. In another case researchers proposed a prediction rule to detect low-risk patients with heart failure by analyzing through classification trees a large data set including parameters such as demographics, clinical, laboratory, electrocardiographic and radiographic results [15]. The same clinical data sets and variables were also used to develop algorithms that perform Bayesian model averaging over a set of models using the characteristics of a specific patient to provide heart failure prediction [16]. Such approaches represent research efforts to develop decision making systems at a laboratory environment and not home-based systems to support early CHF risk detection by using ambient assisted living technologies.

Finally, a number of home-based wearable real-time monitoring systems have been proposed by researchers for continuous medical care of patients [17–19]. However, most of such systems collect, process and transmit vital measurements to healthcare experts in order to remotely monitor their patients, but they generally don't detect CHF risks within the collected data. This is the main difference compared to our system.

3 Multi-parameter Analysis

A risk detection algorithm that performs multi-parameter and multi-level data analysis in order to detect dangerous situations for patients with chronic heart failure is the core of the proposed system. Figure 1 depicts the overall structure of the risk detection algorithm for CHF patients. Multi-parameter data analysis involves a combination of medical measurements and clinical history. Medical measurements include systolic/diastolic blood pressure, heart rate, blood oxygen saturation and electrocardiograph. The clinical history includes clinical measurements specified in the European System for Cardiac Operative Risk Evaluation (EuroSCORE) model that are used in order to calculate the patient risk according to the logistic formula given by EuroSCORE II [20].

The data processing is performed at multiple levels including: (i) medical analysis of measurements based on decision rules which use threshold values specified by medicine science; (ii) statistical analysis of biological data to detect considerable variations between the current measurements and the corresponding medical history data of the same patient; (iii) clinical history data processing which uses EuroSCORE II risk calculation as a method to assess the health risk status for patients that have been operated for heart failure; and (iv) a Bayesian reasoning network which gets as evidence variables the output of the medical analysis and the EuroSCORE II risk

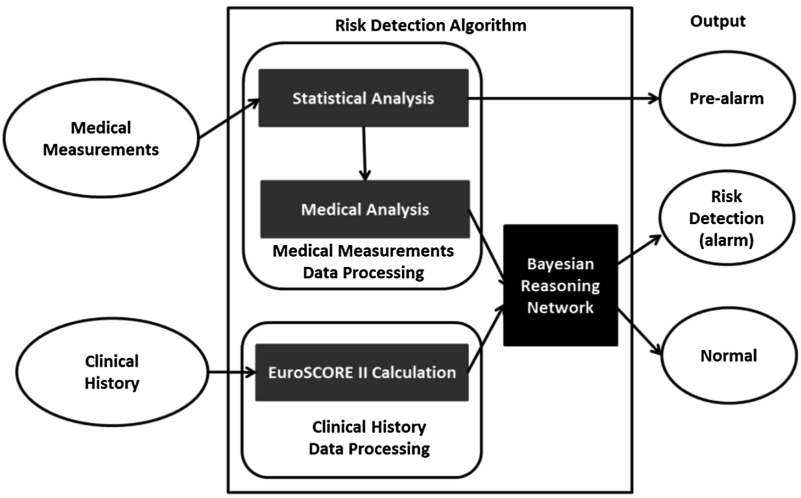

Fig. 1. Multi-parameter, multi-level data analysis for CHF risk detection.

calculation to assess an overall risk level. On the output pre-alarm indicates initial evidence which is not considered critical but should be taken into account for further assessing patient's health state. Alarm indicates evidence that is considered as an emergency for patient's health and requires immediate intervention.

In the following sections we briefly present the various levels of data analysis. A more elaborated description given by the authors can be found in [21].

3.1 Medical Data Processing

In this category of data processing medical measurements are taken regularly at home. As shown in Fig. 2, there are two data processing steps applied by the risk detection algorithm on the medical measurements before outcomes are provided as evidence variables in the Bayesian reasoning network: statistical and medical analysis.

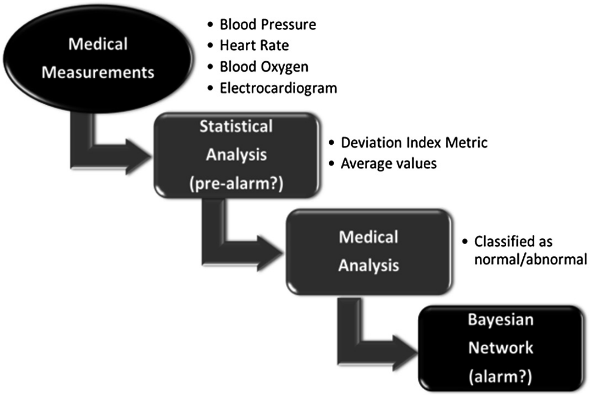

Fig. 2. The medical data processing flow.

The statistical analysis step of the risk detection algorithm uses the deviation index (DI) metric, which is the z-statistic quantity of Statistical Theory measuring the deviation of the measured value of a variable x, from the average value μ of the same variable in standard deviation σ units of its distribution [22]:

$$\mathrm{DI} = \frac{\mathrm{x} - \mu}{\sigma} \tag{1}$$

A high value of instant DI corresponds to a significantly differentiated measurement in relation to the history of the measurements and thus this is assessed as a component of the pre-alarm status for a patient. The deviation index value for a variable x is then categorized based on medical expert empirical knowledge according to the formula [21]:

$$\mathrm{CDI}_x = \left\{ \begin{array}{ll} 0 & \mathrm{DI} \leq 1.5 \\ 1 & 1.5 < DI \leq 3 \\ 2 & \mathrm{DI} > 3 \end{array} \right\} \tag{2}$$

For DI > 3 the observed value occurs with probability less than 0.3% and this signifies a strong pre-alarm. For 1.5 < DI $\leq$ 3 the observed value occurs with probability approximately 13% and signifies a moderate pre-alarm. For DI $\leq$ 1.5 the observed value occurs with probability approximately 87% and signifies a normal state. The output values of the statistical analysis are fed to the medical analysis component for further processing.

The medical analysis step of the risk detection algorithm examines whether medical variable measurements are exceeding normal value ranges in order to be classified as normal or abnormal based on criteria related to the patient profile (Table 1).

Table 1. Medical parameters and their normal value ranges [21].

Parameter	Normal range
ECG QRS width/amplitude	60–110 ms/ $\leq$ 1 mV
ECG P-wave width/amplitude	80–110 ms/ $\leq$ 0.1 mV
ECG T-wave width/amplitude	160–200 ms/ $\leq$ 0.25 mV
Heart rate	60–100 bpm
Systolic pressure	100–130 mmHg
Diastolic pressure	60–85 mmHg
Blood oxygen saturation	96%–100%
Temperature	36.1°C–37.4°C

The Electrocardiogram (ECG) signal is a basic parameter giving evidence of the electrical activity of the heart. Figure 3 shows a typical ECG signal with its constituent segments identified as the P wave, the QRS complex and the T wave referring to depolarization or repolarization of the heart [23]. The R-R interval variable denotes the time between two consecutive R waves and a time series of this variable is used to calculate heart rate in beats per minute (bpm).

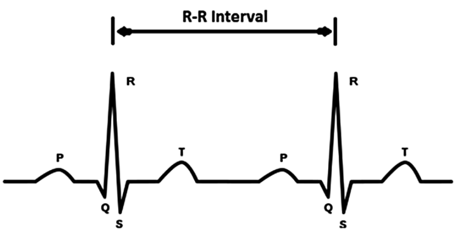

Fig. 3. ECG waveform.

3.2 Clinical History Data Processing

Clinical history is classified into three data categories: risk factors related to the patient, to the heart health and finally to the heart operation, as defined in EuroSCORE II model [20]. As shown in Fig. 4, the risk detection algorithm in this data processing

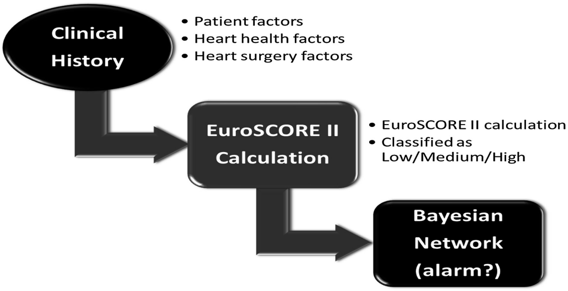

Fig. 4. The clinical history data processing flow.

component calculates the EuroSCORE II risk and then categorizes it as low, medium or high before feeding it as evidence variable in the Bayesian reasoning network.

The following formula calculates the patient risk as defined by the EuroSCORE II model [20]:

$$eSCORE = \frac{e^{\left(\beta_0 + \sum \beta_i + x_i\right)}}{1 + e^{\left(\beta_0 + \sum \beta_i + x_i\right)}} \tag{3}$$

where e the natural logarithm base, β_0 equals to −5.324537, x_i is a binary variable representing a specific risk factor and β_i is the variable's corresponding coefficient as defined in [20]. The calculated value is then categorized according to the following formula suggested by the euroSCORE model and is fed to the BN [21]:

$$eSCORE^{'} = \begin{cases} LOW & if\ eSCORE < 0.03 \\ MEDIUM & if\ 0.03 \leq eSCORE \leq 0.07 \\ HIGH & if\ eSCORE > 0.07 \end{cases} \tag{4}$$

3.3 Bayesian Reasoning Network

The basic concept in BNs is that probabilities can be assigned to variable values and by applying the Bayes laws these probabilities can be updated given new measurements [12]. There are two main methods for constructing BNs when trying to model a particular situation (Fig. 5). The first is the knowledge representation approach, in which the domain knowledge is captured into a BN with the assistance of the domain expert. The second method is based on learning from data, where the structure, the probabilities or both can be learned from a given database.

The lack of adequate clinical data as well as the need of having less computational demands and smaller model in size guided us to construct the BN by surveying the relevant literature and consulting the domain experts. Moreover, with this approach we can have a significant amount of discrete binary variables, allowing us to benefit from computational techniques.

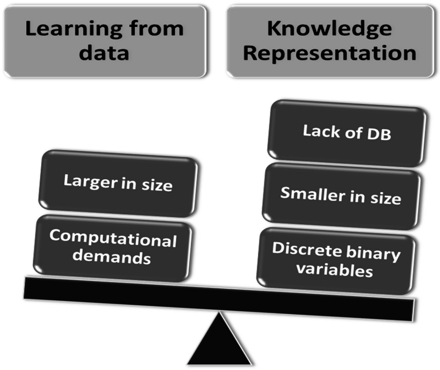

Fig. 5. Bayesian network design options.

Given a problem domain one needs to define the BN model structure. CHF disease, in our case, is related to many causes and effects [24]. Relevant literature was explored to determine parameter dependencies and the original conditional probabilities employed in the BN model [11, 25, 26]. For instance, we found that the prognostic importance of systolic and diastolic blood pressure is well known [28]. Moreover the heart rate parameter is also considered as a predictive factor of CHF risk for seniors whereas the ECG parameter establishes a diagnostic factor. Besides the knowledge extracted by surveying medical studies, in-depth discussions with medical experts provided the proper guidance in order to streamline the network with only the variables that are appropriate in the specific problem domain, to fine-tune conditional probabilities in specific edges of the BN model and to specify validation rules for detecting a CHF risk. Nevertheless, an important factor for choosing the basic BN variables was their appropriateness with respect to gathering the relevant medical measurements in a home environment.

So, in our constructed model there are five evidence variables. Four of them represent categorical medical variables provided by the medical analysis phase, which can take one out of two values abnormal/high or normal. The fifth is the categorized EuroSCORE II risk value derived by Eq. (4), which can take one of three values low, medium, high. For the calculation of conditional probabilities and because both parent and child nodes in the BN model are binary variables we can assume a causal independence among the modeled causes and their common effect and therefore we can apply the Noisy-OR model. According to this model each of the parent variables γ_i is considered as a possible cause of the child variable π, which can cause the effect by itself, with a certain probability p_i. Then the probability that the child variable is TRUE is given by the following equation [21]:

$$p(\pi = \{T\} | \gamma_i) = 1 - \prod_{\gamma_i \in \Gamma_{\mathrm{T}}} (1 - p_i) \quad (5)$$

where the product contains only the factors corresponding to parent variables that are TRUE ($\gamma_i \in \Gamma_{\mathrm{T}}$).

In our case we use a variant of the Noisy-OR model called the *leaky Noisy-OR* approach which attempts to solve the practical problem that not all causes of an effect can be modeled in a BN [29]. This model uses the notion of p_{leak}, which is the total probability of the causes that have not been modeled and can be regarded as one of the causes which may cause the result. In this case Eq. (5) is updated as follows [21]:

$$p(\pi = \{T\}|\gamma_i) = 1 - (1 - p_{leak}) \prod_{\gamma_i \in \Gamma_T} (1 - p_i) \tag{6}$$

Figure 6 shows the probabilities of each variable in the case when no evidence is provided, i.e. the risk probability calculated by the model reflects only the input probabilities of the variables.

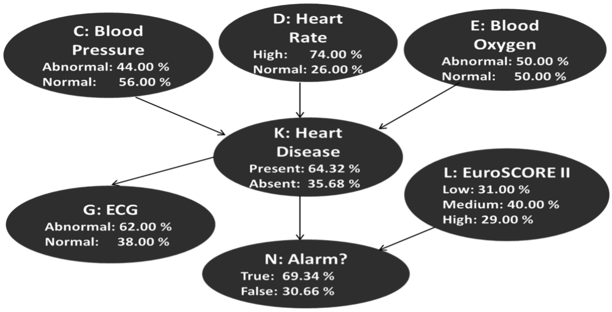

Fig. 6. Bayesian network structure for CHF risk detection when no evidence is given.

Conditional Probabilities. Prior probabilities of nodes in the BN model representing the medical variables “Blood pressure”, “Heart rate” and “ECG” were defined according to the study of Ghosh and Valtorta [11]. Table 2 summarizes the Normal value probability for these nodes.

Table 2. Prior probabilities of medical variables based on literature [21].

BN node	Variable	Probability
C	Blood pressure	0.56
D	Heart rate	0.26
G	ECG	0.38

Blood oxygen is associated with other diseases so there are equal chances of influence. For this reason the prior probability of node (E) was set to 0.5.

Prior probabilities of node “EuroSCORE II”, were defined based on EuroSCORE model data as follows: p(L = {LOW}) = 0.31, p(L = {$MEDIUM$}) = 0.40 and p(L = {$HIGH$}) = 0.29.

The CPT of node K "Heart Disease" given nodes C, D and E was defined using the leaky Noisy-OR formalism. Table 3 gives the contents of the CPT using $p_{leak} = 1 - 0.93 = 0.07$, where 0.93 is the probability of state "Present" in node K when all parent nodes are in "Abnormal" state. The conditional probability of node G given node K is defined as: $p(G|K = \{PRESENT\}) = 0.95$.

Table 3. CPT of node K "Heart Disease" [21].

C	D	E	K
Abnormal	Abnormal	Abnormal	0.93
Abnormal	Abnormal	Normal	0.86
Abnormal	Normal	Abnormal	0.74
Abnormal	Normal	Normal	0.48
Normal	Abnormal	Abnormal	0.88
Normal	Abnormal	Normal	0.76
Normal	Normal	Abnormal	0.54
Normal	Normal	Normal	0.07

The CTP of node N "Alarm" given nodes K and L (Table 4) was defined using the Total Probability Theorem as described by the following equation:

$$p(N|K, L) = p(K)p(N|K) + p(L)p(N|L) \tag{7}$$

Typically the alarm outcome given that the heart disease is present can be set to 0.99.

Also based on the EuroSCORE model data from the 698 deaths, 36 were low risk patients, 182 were medium risk patients and 480 were high risk. So we have the following probabilities per category: $p(N|L = \{LOW\}) = 0.05$, $p(N|L = \{MEDIUM\}) = 0.26$ and $p(N|L = \{HIGH\}) = 0.69$.

Table 4. CPT of node N "Alarm" [21].

K	L	N
Present	Low	0.71
Present	Medium	0.80
Present	High	0.89
Absent	Low	0.02
Absent	Medium	0.11
Absent	High	0.20

4 System Development

In this section we discuss the development of an integrated telemedicine system for supporting CHF patients at home by addressing the early detection and management of health risks. The system developed follows a multi-tier client/server architecture.

The advantages of this model refer to the scalability, reusability and maintenance capabilities provided. The system architecture diagram is given in Fig. 7 and its structure consists of six separate layers, three in the client-side and three in the server-side. In the client-side the system collects biomedical measurements using devices and sensors in the user's home space under the supervision of the Local Subsystem Manager (LSM) which after performing local filtering and formatting of the gathered information forwards it to the remote server that can make assessments about the patient's health status. This multi-layer scheme makes integration of new devices and sensors easier and also facilitates the integration of different technologies that may be used between the layers.

To demonstrate the usage of such a system an indicative scenario is given. A CHF patient following the doctor's instructions takes regularly specific measurements (e.g., blood pressure). The data is collected by the LSM through the device's communication protocol (e.g. Bluetooth). LSM packages the data into a secure JSON envelope and sends it to the server. The server combines the data with past measurements (e.g., taken during the past week/month) and analyses the patient's health status by applying the risk detection algorithm described in Sect. 3. The system may assess that there is a possibility of health risk, and as a response sends a message back to the LSM for a pre-alarm warning and communicates with the local administrator. When the local system receives the pre-alarm message, warns the user to communicate with the doctor because the measurements have been out of balance lately.

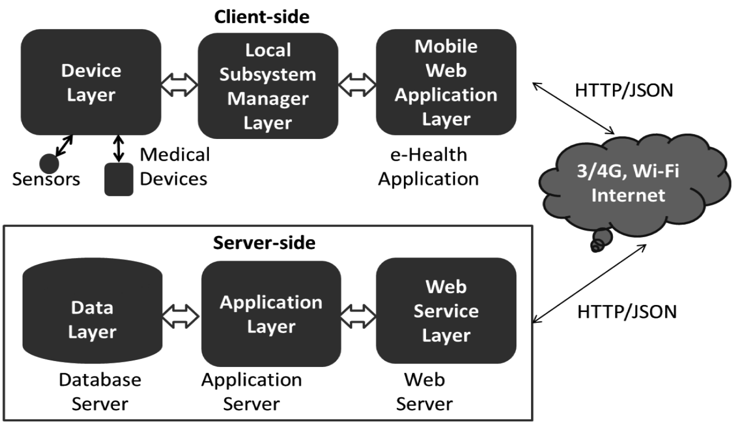

Fig. 7. Multi-tier client/server architecture.

4.1 Client-Side

In this section we describe the layers of the system implemented in the client-side.

Device Layer: This layer includes all the devices and sensors measuring medical parameters (Table 5). These are mainly wireless devices (e.g. Bluetooth) that transmit the data to the LSM through which it can be transmitted with web connectivity to the remote server for storage and processing with the algorithms for medical diagnosis. The basic selection criteria for the devices are:

(a) Openness (i.e. the device has to provide an Application Programming Interface (API) for direct downloading of data without the mediation of some cloud server).
(b) Reliability via proper certifications (e.g. MED CERT ISO 13485) and
(c) Interoperability (e.g. Continua Product Certification).

Table 5. Medical devices characteristics.

Device	Parameter	Certified	Link
EMB1	ECG	MED CERT ISO 13485	https://www.corscience.com/emb
UC-355PBT-Ci	Weight	Continua-certified	http://www.andonline.com/
CorScience Pulse Oximetry	Blood oxygen saturation	MED CERT ISO 13485	https://www.corscience.com/chipox
AnD Medical UA-767PBT-Ci	Blood pressure	Continua-certified	http://www.andonline.com/

The API of the devices provide raw measurements that can be subsequently be processed by algorithmic techniques in order to extract useful diagnostic features. For example, the Pan-Tompkins algorithm [30] is used to recognize the QRS-complexes in the ECG signal and then the amplitude and duration can be measured in rode to assess the normal or abnormal classification by checking the threshold values defined in Table 1.

Local Subsystem Manager Layer: This layer includes key processes in the client-side of the system which implement the following operations:

- User notification to start a periodic measurement scenario.
- Data gathering from the medical sensors and devices.
- Temporary storage of data in case of network problems in the communication with the server.
- Data validity checking based on the normal value ranges defined in.
- Data forwarding to the server.
- Receiving commands and processed responses (pre-alarms, alarms) from server.
- User notification management through warning messages.

To initiate a regular medical measurement, the LSM creates the proper low level messages to trigger the relevant devices for starting measurements and prepares the appropriate data structures to store the data collected from the devices. Moreover, the LSM updates the graphical user interface to display a set of guidelines to the user for using the devices (Fig. 8).

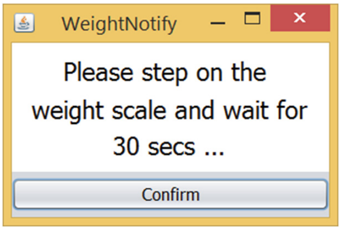

Fig. 8. A typical interaction message with the patient.

Mobile Web Application Layer: This layer provides access to the user profile and stored data. It also provides a personalized view of data as well as access levels depending on whether the user is a patient, medical staff or administrator. Figure 9 shows the main screen of the Web Application.

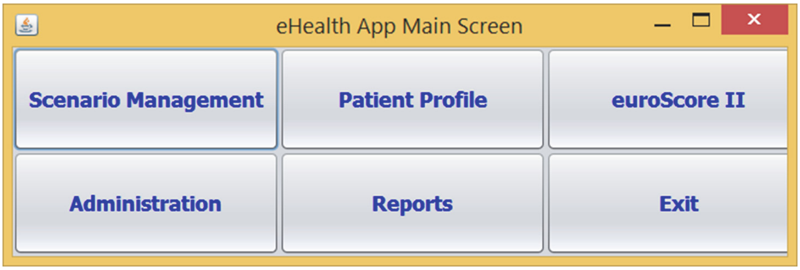

Fig. 9. Main screen of the web Application.

In summary the following functionality is provided:

- An interface to create a new medical measurement protocol/scenario;
- A personal profile interface where the user can enter patients' personal information as well as relevant chronic diseases;
- A GUI to simulate sensor measurements for debugging purposes;
- An interface where the history measured data can be displayed in graphs;
- An interface to manage reports;
- An interface to provide notification to the user;
- An interface to create new users and to define new time periods for measurements and new thresholds for the medical analysis process.

4.2 Server-Side

The remote server provides the ability to interface with one or more clients for monitoring one or more patients and accepting HTTP type requests for storing measurements via a web application. In addition it supports the recording of each patient's profile into the database, decision-making by using a risk detection algorithm that performs multi-parameter and multi-level data analysis to identify emergencies and generate alarms and pre-alarms and finally the generation of suitable reports based on the information stored in the database. Figure 10 illustrates the component diagram of the server.

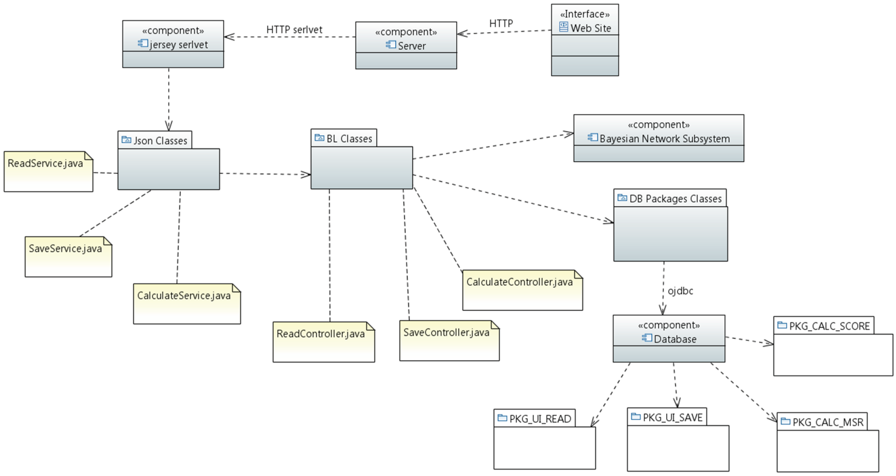

Fig. 10. Server-side system component diagram.

The server is divided into the following logical layers:

Web Service Layer: The components in this layer are responsible for receiving and sending messages from/to the client and also authenticating and validating the http calls and initiating measurement data recording. The communication mechanism is based on sending messages through the HTTP protocol, using the representational state transfer (REST) model.

Application Layer: The main purpose of this layer is to run the health risk assessment algorithm, which may generate pre-alarm or alarm states. More precisely, the received JSON message with the measurements from the client is checked initially for integrity and then the data are stored using the corresponding database package procedures. The EuroSCORE II model procedures are called to perform the calculation of the model result. The risk detection algorithm can then be initiated to check for an alarm or a pre-alarm. In case of abnormality the system either notifies its administrator to contact the patient or sends back to the corresponding client LSM the appropriate notification messages in order to be presented to the user.

Therefore, the application layer contains in the implemented Java classes the business logic of the server-side. In particular, it encompasses the Bayesian reasoning network component and components that interact with the data layer for storing measurements and EuroSCORE values. The application layer performs the following four basic tasks: data retrieval, data storage, patient's EuroSCORE II model calculation and risk detection estimation using the BN.

Data Layer: The data layer contains a relational database which was designed and implemented in Oracle platform. It also includes all the necessary procedures for storing, retrieving, updating and maintenance of data, as well as the necessary mechanisms for ensuring data integrity. The database scheme includes 14 tables with 92 fields in total and 14 relationships between the tables (Fig. 11).

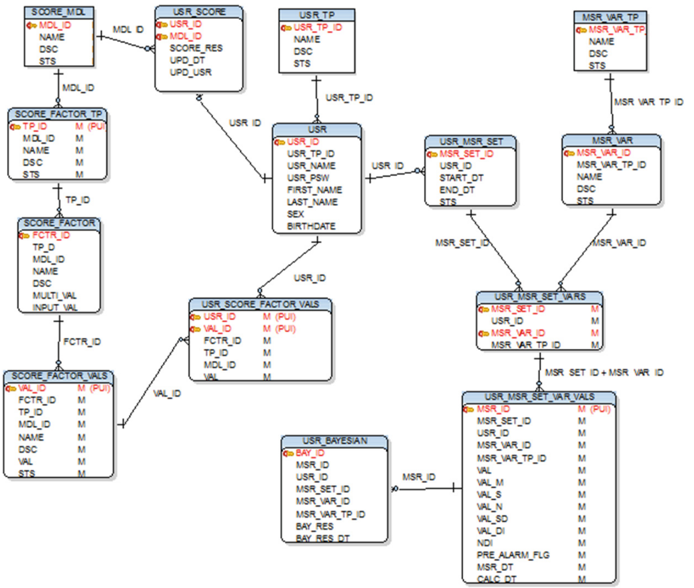

Fig. 11. Database entity-relationship diagram.

The tables are classified into three categories:

EuroSCORE Model Tables. Tables in this category are containing information describing the EuroSCORE related models. The risk detection algorithm uses, in particular, the EuroSCORE II model to determine the degree of patient's health risk. In fact, the corresponding tables in the database have been designed in a general way so that additional risk assessment models related to patient's health can be also supported. Tables in this category are the following:

- SCORE_MDL: This table contains records for all three EuroSCORE models, i.e., additive EuroSCORE, logistic EuroSCORE and EuroSCORE II which is the latest version used by the system.
- SCORE_FACTOR_TP: This table contains records regarding the different data categories per model. For example, EuroSCORE II model has three such categories, namely risk factors related to the patient, risk factors related to heart health and risk factors related to heart operation.

- SCORE_FACTOR: This table contains records with the names and the descriptions of risk factors per category and per model. For example, a risk factor related to the patient in the EuroSCORE II model is the “Extracardiac arteriopathy”.
- SCORE_FACTOR_VALS: This table contains the coefficient for each risk factor that is used in Eq. (3). For example the risk factor “Extracardiac arteriopathy” has a single record with the value 0.5360268.

Medical Measurement Tables. Tables in this category are containing information describing medical protocols for which the system collects measurements. The design of the tables takes into account that these tables may have to store measurements from various sources in the future so that the system can be expandable. The tables in this category are the following:

- MSR_VAR_TP: This table contains records for all types of sensors and devices that may be used for medical measurements. For example, biometric measurements from a Bluetooth oximeter.
- MSR_VAR: This table contains records for all the medical measurements supported by the system per device type.

Users Tables. Tables in this category are containing user-related information such as the medical history and stored measurements. The tables in this category are the following:

- USR_TP: Defining user types (patient, doctor, and administrator).
- USR: Containing users’ profile.
- USR_SCORE: Containing EuroSCORE II model results that have been calculated.
- USR_SCORE_FACTOR_VARS: Containing values of risk factors that have been recorded for each patient.
- USR_MSR_SET: Containing time periods sets for measurements of each patient.
- USR_MSR_SET_VARS: Measurements per time period of each patient.
- USR_MSR_SET_VAR_VALS: Containing detailed measurements of medical parameters collected by sensors as well as statistical values recorded by the system for each patient. Also it contains the number of measurements, the sum of squares, the average value, the standard deviation and Deviation Index which are calculated and recorded every time a measurement is added to the database.
- USR_BAYESIAN: Bayesian reasoning network results calculated for each patient.

Finally, the access to the data is performed through database procedure packages and not directly from table queries for transparency reasons and separation of concerns between the data layer and the application layer. The packages defined are the following:

- PKG_UI_READ: Procedures to retrieve data for the GUI.
- PKG_UI_SAVE: Procedures to update data.
- PKG_CALC_MSR: Procedures to calculate EuroSCORE model and statistical analysis results.
- PKG_BAYESIAN_NET: Procedures to update and store Bayesian network results.

4.3 Measurement Scenario Management

The system administrator can manage the creation/update/deletion of a measurement scenario using the main screen of the Web Application (Fig. 9). A scenario may consist of one or more MEASUREMENT activities and a number of interaction activities like the NOTIFY activity. A NOTIFY activity stores a message content which notifies the user when such activity is executed by displaying the corresponding message on a screen (an example is shown in Fig. 8) and/or by playing an audio message when a speech to voice conversion utility is available. The scenario creation process is assisted by a wizard tool through a number of interaction steps. The administrator has to define for example the basic properties of the scenario such as its name, type and patient risk level (Fig. 12, left screen). A periodic scenario indicates a measurement process that is taken place on a regular basis. Other types include "On demand" and "Test". The former is initiated by the patient while in the latter case measurement values are not stored in the system database. A user interface is provided also to assist the definition of activities sequence in a scenario. Figure 12 (right screen), depicts the summary of a simple scenario that involves a blood pressure measurement activity and notification activities.

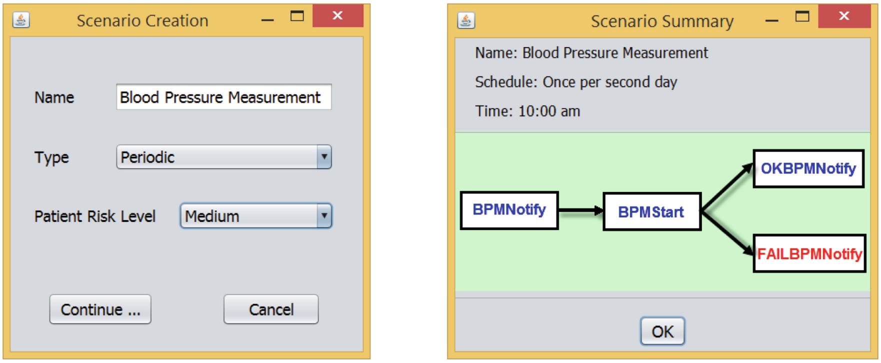

Fig. 12. Scenario creation and summary sample screens.

New activities as components of the scenarios can be defined by the administrator using the provided user interface. For example Fig. 13 shows activity creation for two different activity types.

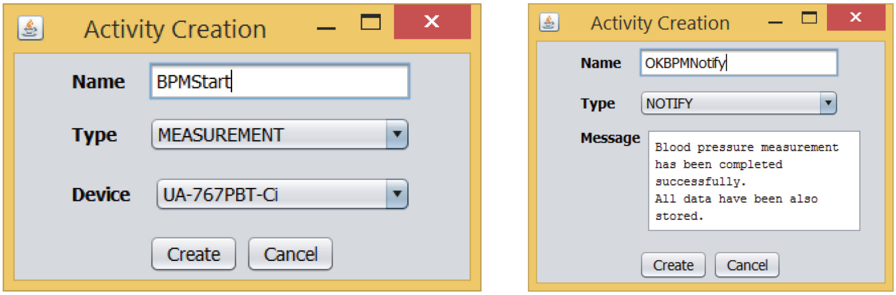

Fig. 13. Activity creation sample screens.

4.4 Implementation Tools

The overall system was implemented using several development technologies and tools. The Java programming language and the Eclipse Mars 2 Integrated Development Environment were used to implement the application layer and the LSM. The wireless communication with the medical devices was based on the Bluetooth stack of the operating system. HTML 5 in combination with the Bootstrap CSS framework were used to develop the web application providing cross-browser compatibility, whereas the jQuery JavaScript library was used to implement the asynchronous calls to the restful web services. Web services were implemented using HTTP and JSON data format for transferring messages between the client and the server.

The Bayesian reasoning component of the risk detection algorithm was designed and tested using a tool developed at University of California at Los Angeles for modeling and reasoning with BNs named Sensitivity Analysis Modeling Inference And More – SamIam [27]. For the development of the Bayesian reasoning component we employed the Jayes library [31].

Lastly, the Oracle database framework, Express Edition 11 g Release 2, was used to implement the relational database.

5 Validation

5.1 System Validation

From a technical perspective, the system validation process was performed in three levels: unit level, function-level and overall process level testing. At the unit level, all modules developed were tested regarding their proper operation including device management by the matching software driver depending on the communication interface employed (e.g. wireless LAN, Bluetooth). At the function-level, specific system functionality was tested like system login, user profile management, activity and scenario creation, data storage, recognition of pre-alarms and alarms, and communication of the client-side with the server-side and vice versa. At the overall process level, the system was tested with respect to cohesion and reliability of the provided functionality when combinations of operations are executed for a long period of time.

5.2 Medical Inference Validation

Medical inference validation was performed in two directions. First, the risk values of the EuroSCORE II model calculated by the system were compared to the values calculated by the on-line EuroSCORE calculator [32] and were found to be equal for the same inputs. Secondly, the predictive validity of the risk detection algorithm was checked. The accuracy of the BN reasoning was determined with the participation of medical experts due to the lack of reliable clinical data to compare with the system predictions. The BN model was also checked regarding the mechanism through which prediction is obtained. As suggested by Pitchforth and Mengersen there are seven dimensions of validity in a BN model that should be examined [33]. Figure 14 summarizes how our BN model satisfied these validation tests.

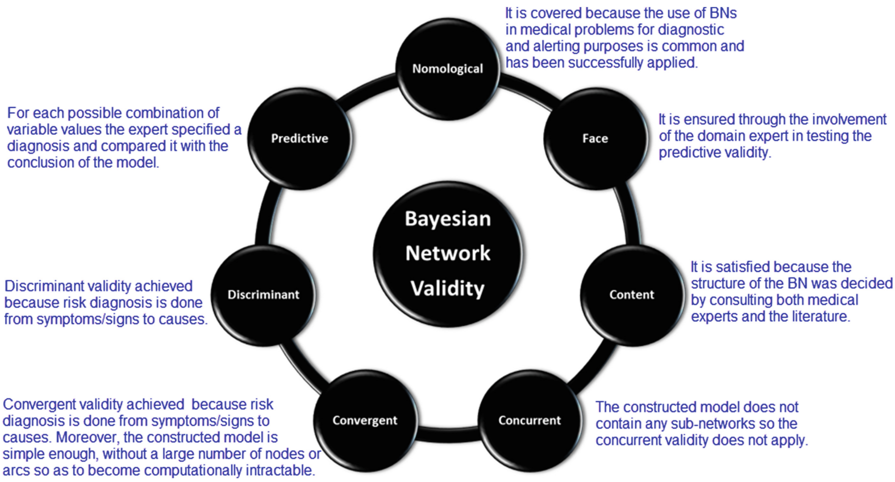

Fig. 14. BN validity tests performed.

In particular, for predictive validity the agreement between the reasoning of the model and the diagnosis made by the domain expert was checked for each possible combination of evidence variable values. In our model there are 48 possible evidence combinations generated from five variables. Four of them represent medical parameters that take one out of two values and the EuroSCORE variable with three values. The process was facilitated by using the SamIam tool to manage the testing of all possible combinations and automatically calculating the probability of the CHF risk. The expert assessed the conclusions of the model as reasonable and also specified the following validation rules for which the CHF risk should always be true:

- Patients with eSCORE risk Low must have all medical measurements Abnormal.
- Patients with eSCORE risk Medium must have at least two medical measurements Abnormal.
- Patients with eSCORE risk High and anyone medical measurement Abnormal.

A critical task was to locate a specific threshold for the probability of CHF risk that divides all the evidence combinations into alarm and no alarm in the same manner as the domain expert. As a result of the analysis, the alarm threshold was found to be sixty-five percent (0.65), in order to generate the alarm. Figure 15 gives a comprehensive view of the BN conclusions according to the eSCORE risk category when different evidences are generated. As it can be observed the generation of an alarm is in accordance to the recommendations made by the expert. As an example, for patients with medium risk and two abnormal measurements, the model calculated an alarm probability of 65.52%, whereas with only one abnormal measurement the alarm probability was 56.54%, which is below the threshold as normally expected.

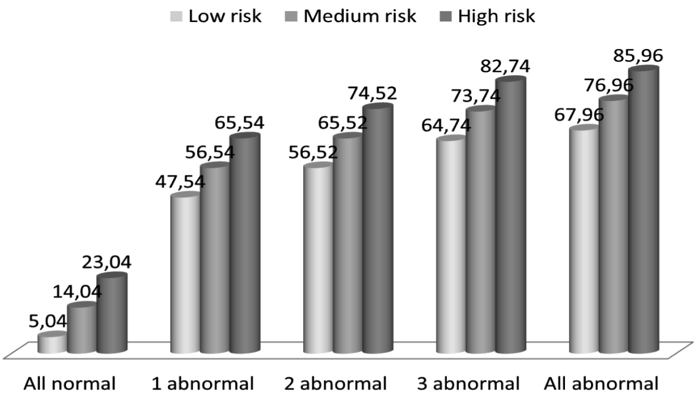

Fig. 15. Bayesian probability result by risk category and medical measurement result.

6 Conclusion and Future Work

Proactive support of CHF patients is vital since the recovery from a critical condition usually presents complications and it is not always possible. Although emergency situations may occur without prior warning, still in the majority of emergency cases, there are "signals" that precede their appearance. The regular monitoring of selected health variables followed by a multi-parameter and multi-level data analysis for the identification of abnormal health trends is the main contribution of the presented methodology.

Today, telecare systems typically incorporate the monitoring of patients' vital signals which can be transmitted, wirelessly, to a public or private medical care center for the provision of healthcare services. Furthermore, many systems support the automatic generation of alarms when the measurements exceed a predetermined range. The presented system surpasses this functionality and provides risk inference capabilities for the specific chronic disease by combing biological signals with a validated risk model. The system integrates additional mechanisms like the scenario creation tool which can facilitate system usage in different measurement situations.

The technical solution has been validated in several levels where as the medical inference component and the associated BN model defined were validated for prediction accuracy with the assistance of the domain expert with positive results.

Although the system presented addresses the problem of early prevention and management of health risks and complications in CHF patients, still with the proper enhancements in the BN modeling and health parameters monitoring the system could be used for risk management in other chronic diseases such as hypoglycemia in patients with Diabetes Mellitus. Our goal is the specification of a general methodological framework on the management of chronic diseases, as a result of the study of more use cases highlighting the perspective of the system to become a generic tool with built-in medical inference capabilities for various diseases. This aim needs to be validated in clinical trials using the integrated system with patients at their home.

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ICT-Supported Interventions Targeting Pre-frailty: Healthcare Recommendations from the Personalised ICT Supported Service for Independent Living and Active Ageing (PERSSILAA) Study

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Abstract. As society ages, healthcare systems are preparing for an increasing prevalence of frail, co-morbid and older community-dwellers at risk of adverse outcomes including falls, malnutrition, hospitalisation, institutionalisation and death. Early intervention is desirable and pre-frailty, before onset of functional decline, may represent a suitable transition stage to target, albeit evidence for reversibility and appropriate interventions are limited. No consensus on the definition, diagnosis or management of pre-frailty exists. This work describes 25 healthcare related findings from the recently completed PERsonalised ICT Supported Service for Independent Living and Active Ageing (PERSSILAA) project, funded under the 2013–2016 European Union Framework Programme 7 (grant #610359). PERSSILAA developed a comprehensive Information and Communication Technologies (ICT)-supported platform to screen, assess, intervene and then monitor community-dwellers in two regions (Enschede in the Netherlands and Campania in Italy) in order to address pre-frailty and promote active and healthy ageing, targeting three important pre-frailty subdomains: nutrition, cognition and physical function. Proposed definitions of pre-frailty, ICT-based approaches to screen and monitor for the onset of frailty and targeted management strategies employing technology across these domains are described. The potential of these 25 healthcare recommendations in the development of future European guidelines on the screening and prevention of frailty is explored.

Keywords: Pre-frailty · Frailty · Information and communication technology Healthcare recommendations · Guidelines

1 Introduction

Recent trends associated with demographic ageing have resulted in an increased prevalence of older adults, aged >65 years [1]. With this, health and social care providers and policy makers are recognising a higher prevalence of frailty in community-dwelling older adults [2]. Although no consensus definition of frailty is accepted, most consider it to be a multi-factorial, age-associated loss of physiological reserve characterised by an increased vulnerability to stressors that results in a propensity for adverse healthcare outcomes [3–6]. Estimates of prevalence differ depending on the population studied, sampling strategy employed and frailty classification applied. Reflecting this, reported frailty rates for persons aged over 65 years varies from 6.9% or lower in large population-based studies [7] to as high as 75% in primary care cross-sectional samples [8]. Data similarly vary by region with higher levels found in developing countries [9] compared with more developed nations [2].

The choice of frailty classification is also important with two main approaches commonly used to define frailty: the Frailty Phenotype [7] and the Frailty Index. Fried's Frailty Phenotype characterised by physical signs and symptoms suggesting frailty classifies individuals as frail if they meet three or more of the following five criteria: weight loss (>5% in last year), exhaustion, weakness (decreased grip strength), slow walking speed (>6 to 7 s for 15 feet), and decreased physical activity (males <383 kilocalories; females <270 kilocalories) [7]. Modified versions exist that deviate slightly from this initial description. The Frailty Index is characterised by an accumulation of deficits identified from a list of predefined variables that are used to create a proportion or decimal from 0 (no deficits) to 1 (maximum number of deficits present) [10]. Multiple indices are available with varying numbers of deficits. While complementary, they measure different constructs [11] with Fried's phenotype usually reporting lower prevalence rates [12]. A recent systematic review of the weighted prevalence of frailty from cross sectional data in community-based cohorts of older adults aged ≥ 65 estimated that the overall weighted prevalence was 10.7% [2]. In addition, many other factors impact upon the prevalence of frailty such as sex and socioeconomic status [13]. For example, 8.5% of women in the European Union (EU) aged between 65 and 74 years are frail compared with 4.1% of males [14]. Within the EU the prevalence of frailty in community-dwelling older adults aged over 65 years varies between studies with data suggesting that between 5.8% and 27.3% [15] are frail.

Pre-frailty, is a prodromal 'risk' state before the onset of frailty. However, no definition of pre-frailty is established or widely used. Instead, a cut-off score on a frailty screen or frailty assessment scale defines it as an intermediate level before the development of functional decline. For example, a score of one or two on the Fried's Frailty Phenotype denotes pre-frailty. The proportion of frail, older adults living in the community is variable depending on the sample and setting but can reach half [2]. Many more, up to 60% of those aged over 65, can be classified as pre-frail [15], though again this depends on the approach used to categorise pre-frailty [16].

While the development of frailty is often considered permanent, evidence suggests it is a dynamic process with some patients converting from frail to pre-frail and even becoming robust again [17]. Despite this, once established, frailty is difficult to reverse [18] with less than 1% of persons considered frail becoming robust over five years [17]. Given that frailty is associated with an increased incidence of chronic medical conditions [19, 20], hospitalisation [21–23], readmission to hospital after discharge [24], higher healthcare costs [25], institutionalisation [3], and death [26], there is a need to promote active and healthy ageing and instigate measures to prevent frailty [6, 27–30].

From a practical perspective targeting pre-frailty is a reasonable approach, though at present there is insufficient evidence to support this [31]. Specifically, the use of multi-factorial interventions to screen, monitor and manage prodromal states related to pre-frailty such as mild cognitive impairment [32–34], or reduced physical activity in the presence of sarcopenia [35, 36] appear most appropriate. Likewise, combinations of targeted, coordinated and preventative interventions delivered in the community can reduce adverse healthcare outcomes [37]. Recently, data from intervention studies targeting pre-frailty has shown the potential for using combined physical and nutritional interventions to delay or prevent onset of frailty, though compliance with the intervention can often be suboptimal or unclear [38]. While there is growing interest and uptake in the use of information and communications technology (ICT) by older adults, the presence of frailty affects these persons′ ability to access and utilise technological devises [39]. Some limited data suggests that incorporating complex interventions such as physical exercise regimes into ICT devises may improve compliance and produce positive effects on quality of life [40]. The goal of using ICT to either prevent onset or progression of frailty is included in the action plan of the European Innovation Partnership on Active and Healthy Ageing [27] and centres around the construct of recognising functional decline manifest by impairment in activities of daily living (ADL), an older person-important outcome.

As few studies have used frailty as an outcome measure [41], the overarching aim of PERsonalised ICT Supported Services for Independent Living and Active Ageing (PERSSILAA) was to examine whether frailty can be prevented and whether an ICT-based intervention designed to target pre-frail community dwelling older people can delay onset of frailty and functional decline. Specifically, although some data on individual or combined interventions exists, no study has examined the use of a multi-domain, ICT supported platform targeting pre-frailty in its ability (utility and feasibility) to prevent functional decline and subsequent onset of frailty. Similarly, while several national and international Geriatric and Gerontological societies provide best practice recommendations for addressing frailty [6, 42], given the paucity of studies, no guidelines exist for the management of pre-frailty.

2 Overview of the PERSSILAA Project

The PERSSILAA project was funded under the European Commissions' Framework Programme 7 between 2013 and 2016, (see grant number 610359). It consisted of a consortium of eight partners from five EU countries from across the medical, social and technological sciences as well as including partners from industry, academia and end-user organisations. The primary objective of PERSSILAA was to develop an ICT-based platform to identify and manage older community dwellers at risk of functional decline and frailty (i.e. pre-frail older adults) to determine if such an intervention could influence frailty trajectories. This multimodal service model focuses on three core frailty domains, specifically nutrition, cognition and physical function. Supported by an interoperable ICT service infrastructure, PERSSILAA uses an intelligent decision-support system and gamification strategies to encourage end-users to engage with the platform. PERSSILAA was designed specifically for older community dwellers aged over 65 who as part of the project were (1) screened by a trained rater or were self-assessed to identify and stratify them according to their frailty status, (2) triaged or stratified to the appropriate ICT-based solution to meet their needs (targeting one, more or all three frailty domains), (3) monitored (unobtrusively) to identify their trajectory of ageing and (4) managed with ICT supported services through local accessible community structures.

The design of the study is described in more detail elsewhere and below but in summary, an 'ideal' service model was developed and refined through a series of meetings with older adults taking a participatory design and iterative approach [43]. An important outcome of this initial work was the need to offer multi-modal screening, stratification and management strategies to older patients, as they are a heterogeneous group with different skills and expectations [43]. The need for education, particularly with respect to ICT skills was highlighted, as was the need for older adults themselves to direct their own management and for participants' primary care physicians to be informed without creating additional burden (i.e. integrating the process and results).

Thus, the PERSSILAA screening and intervention modules consisted of both face to face and remote (postal and online ICT) components. Suitable participants identified in one of the two evaluation sites, Enschede in the Netherlands and Campania in Italy, were screened for frailty using a two-step screening process. Initially a brief pre-screen (conducted by post, online or in person) was performed. This was followed by a more detailed assessment in person to confirm their status for individuals screening positive for pre-frailty (i.e. the target group). In Enschede, older adults aged 65–75 recruited through primary care, selected by their family doctor were recruited. In Campania, older adults aged over 65 were recruited through local church communities, selected by the Naples Curia Diocesana. Once identified as pre-frail, PERSSILAA services targeted specific trainings modules for both health and ICT (ehealth) literacy and where appropriate, based on the screening and triage component, were used to provide physical training, cognitive training (Guttmann NeuroPersonalTrainer®) and nutritional advice (NUTRIAGEING™ website) to participants. PERSSILAA services were designed to be accessible and thus were offered in multiple formats i.e. in person or online via personal or tablet computers, so older adults could use them with supervision or independently. To enhance the user experience and encourage compliance, in addition to a standard version, a gamified version was also developed, which while designed to be fun and interactive, encouraged on-going participation, also known as 'serious gaming'. For example, in one version older adults were encouraged to build a boat to escape from a virtual island but could only gather the pieces required if they used the trainings modules. Gamification is shown to encourage older people to use telemedicine [44], generate more engaging assessment strategies, [45] and can be used to promote and motivate behaviour to support lifestyle change [46]. The project also investigated the degree to which the PERSSILAA platform was acceptable, efficacious and ultimately effective to real world users in a real world setting, in preventing onset of frailty among pre-frail older adults. As this was an evaluation rather than a validation study, the priority was to show acceptability and proof of concept. PERSSILAA services were studied in two different populations of older people in two of the partner countries, Italy and the Netherlands. To maximise the results two different evaluation studies were performed. In Campania, a prospective cohort study was conducted to examine the uptake, acceptability and usability of the platform among older Italians. In Enschede, a multiple cohort randomised controlled trial (mcRCT) design was applied and 82 participants in the Netherlands were recruited, of whom half (n = 46) received the intervention. Cost effectiveness was assessed with the Monitoring and Assessment Framework for the European Innovation Partnership on Active and Healthy Ageing (EIP on AHA) tool [47]. The project was funded to last for three years. All participants provided informed consent prior to being included and then assessed at baseline, scheduled intervals and the end point. Additional details including a full list of publications can be found at: www.perssilaa.eu.

3 Recommendations from the PERSSILAA Project

The main results of the project were subdivided and examined by topic to provide recommendations on addressing frailty and functional decline through the identification and targeting of pre-frailty. Results were grouped to be of interest to a broad interdisciplinary audience and developed by the consortium as a whole, led by individual partners according to their area of expertise. These were broadly categorised into three themes: (a) Healthcare related recommendations, (b) ICT related recommendations and (c) Organisational (institutional) recommendations. This work reviews and summarises the healthcare specific findings derived from the project. To compile these, partners were tasked according to their relevant specialty to develop related recommendations based on the work completed during the project. There are several recommendations within each theme. The results presented here describe the clinically (healthcare) relevant outcomes of the study that could be used to contribute to the development of guidelines for the screening of and prevention of frailty in older EU citizens.

3.1 Definition of Pre-frailty

Although pre-frailty is usually identified as a prodromal state before frailty and subsequent functional decline develop, no clear definition of pre-frailty exists. As part of the project the investigators performed a narrative, state of the art literature review to examine existing definitions of frailty and pre-frailty. As with frailty, no consensus definition was found. Instead, pre-frailty is most often characterised by reference to frailty and classified as a transitional stage on the trajectory from full independence (robust state) to increasing functional dependence (frailty). Pre-frailty, like frailty is measured by several short-screening instruments but is defined by a cut off score below that for frailty. For example, pre-frailty is present when one or two of the Fried frailty phenotype characteristics are present. It is proposed that identifying this prodromal phase at an early stage will allow the introduction of measures to prevent onset of frailty [28]. In order to select a sample, the PERSSILAA investigators adopted a definition of pre-frailty consistent with the goals of the project. After reviewing several possible definitions, a multi-domain definition targeting the key frailty domains. Given that many of the consortium were also member of the EIP on AHA A3 Action Group on frailty prevention, the definition of pre-frailty used in PERSSILAA was based on an adapted version of the A3 groups' definition of frailty [48]. This definition describes pre-frail older adults as those *at an increased risk of poor clinical outcomes, such as the development of disability, dementia, falls, hospitalisation, institutionalisation or increased mortality* where one or more pre-frailty states (e.g. mild cognitive impairment, sarcopenia, physical and functional impairment, dysthymia and social isolation) is evident.

Recommendation: *Pre-frailty should be considered a multi-domain, multi-factorial syndrome.*

Recommendation: *The EIP on AHA definition of frailty could be adapted to define pre-frailty.*

Recommendation: *The EIP on AHA A3 action group are ideally placed to take the lead in developing a definition of pre-frailty to support and stimulate debate on a consensus definition of this important prodromal condition and emerging public health priority.*

3.2 Screening for Pre-frailty

Multiple short screening instruments to identify frailty are currently available and in use in clinical practice [49]. Despite this, no single instrument is currently recommended, likely relating to differences in approaches to identify frailty syndromes [6]. Further, only a few instruments are able to accurately differentiate pre-frailty from frailty. PERSSILAA was predicated on a two-step screening and assessment strategy in an attempt to correctly categorise participants as pre-frail (i.e. the target condition). This was modified during the project where redundancy was identified. Screening followed by more comprehensive assessment is recommended given the expected high prevalence of pre-frailty in community samples, the relative high sensitivity but low specificity of the screening instruments and the resources required to screen in this setting [50]. Instruments were selected following a literature review. Thus, the two stage selection process involved (1) the screening of people ≥ 65 years by trained volunteers/self-screening by email or postal questionnaire to exclude robust subjects and those with established frailty and (2) a face to face assessment by trained multi-disciplinary staff of those classified as pre-frail in order to confirm if they were pre-frail. Each domain included in PERSSILAA was screened using this approach.

The screening and assessment instruments used at each stage are presented in Fig. 1. During the first iteration (the first round) the scales were rationalised producing a more streamlined final version. Screening began in 2014. In overview, the first step divided participants into robust, pre-frail and frail using a ‘global’ frailty scale combined with individual measures of nutrition, cognition and physical function. The Groningen Frailty Indicator (GFI), a 15-point yes-no questionnaire exploring physical, cognitive, social and psychological components of frailty was used as a global measure, using a cut-off of $\geq 4/15$ for moderate-severe frailty [51]. The INTERMED was initially trialled but did not provide sufficient additional information to justify its inclusion. Instead, the GFI was used alone in the final version given that it is shorter and already validated in all the languages of the project. Participants were further screened using instruments specific to the selected pre-frailty domains using stage specific cut off scores. The final instruments selected were the Mini-Nutritional Assessment (MNA) short form to identify nutritional deficits, the 8-item Alzheimer’s disease 8 questionnaire (AD8) for cognitive deficits and the Short-form 36 questionnaire (SF-36) to screen for physical impairment. The KATZ activities of daily living (ADL) scale and the Quick Memory Check (QMC), initially trialled during the first iteration were considered to be too impractical for self-screening. In the second step (face-to-face assessment), older adults were evaluated to confirm if they were pre-frail. Nutritional deficits were identified with the remainder of the MNA (G-R), cognitive impairment with the Quick Mild Cognitive Impairment (Q*mci*) screen [52–59] using age and education adjusted cut-offs [60], and physical function using the short physical performance battery (using the Timed Up-and-Go Test, the Two-Minute Step Test, the Chair-Stand Test, and Chair-Sit-and-Reach Test).

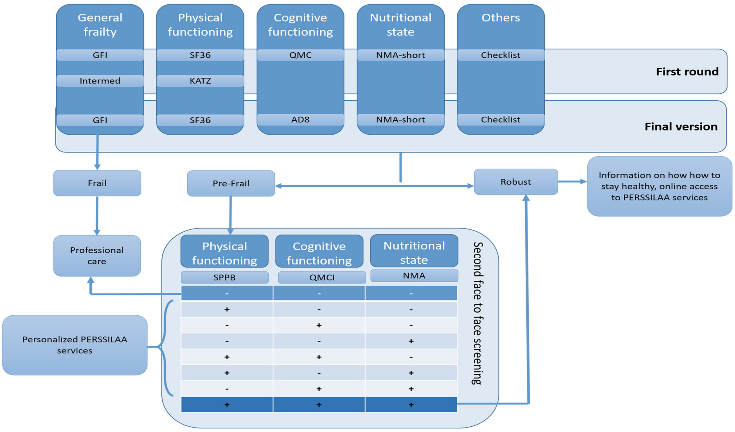

Fig. 1. Two-step screening protocol for the PERSSILAA project showing the first and final version of the first screening step [61].

The results showed that the PERSSILAA screening service with the addition of demographic data is useful in quickly and accurately classifying older community dwellers as robust, pre-frail or frail. In all, 4071 participants were screened. The majority of these participants (n = 2,438) were classified as robust (60%). An additional, 916 (23%) were characterised as having a high probability of being pre-frail and were thus suitable for further assessment (step two). There were no significant differences in age though frail patients were more likely to be female. The baseline characteristics of patients are presented in Table 1, below.

The face to face assessment (second step) confirmed that of those screening positive for pre-frailty, that 90% were pre-frail. Logistic regression showed that those screening positive were truly pre-frail and showed that the first-step screening process had an overall good to excellent accuracy (area under the curve of 0.87 with a moderate to high sensitivity (77%) and specificity (84%). Analysis of the face to face assessment showed good agreement among the classifications of pre-frail and robust individuals. These results suggest that the two-step screening and assessment approach developed for PERSILLAA was able to correctly categorise pre-frail community-dwelling older adults.

Statistical assessment of accuracy using receiver operating characteristic curve analysis showed that the MNA (assessing nutrition) was the most accurate individual

Table 1. Characteristics of participants included in baseline screening by frailty classification.

Variable	Robust	Pre-frail	Frail	Total
Number of participants	2438	916	717	4071
Age (± standard deviation)	69.71 ± 4.18	70.44 ± 4.71	70.82 ± 5.97	70.06 ± 4.63
Gender (% female)	48%	56%	61%	52%
Groningen frailty indicator (± standard deviation)	0.97 ± 1.08	2.49 ± 1.36	6.35 ± 1.56	2.24 ± 2.33
Alzheimer's disease 8 questionnaire (± standard deviation)	0.19 ± 0.39	1.03 ± 1.28	1.86 ± 1.91	0.66 ± 1.22
Short-form 36 questionnaire for physical impairment (± standard deviation)	91.57 ± 9.89	65.33 ± 26.36	54.88 ± 29.86	79.21 ± 24.71
Mini-nutritional assessment – short form score (± standard deviation)	11.71 ± 1.04	10.36 ± 1.66	9.52 ± 2.53	10.70 ± 1.67

predictor of pre-frailty with an area under the curve of 0.80, indicating good accuracy, supporting the known important role nutrition plays in the development of frailty [62].

Recommendation: *Multiple pre-frailty sub-domains should be addressed when screening for and assessing pre-frailty among older adults and should include cognitive, physical, nutritional, social and other domains.*

Recommendation: *More research is required in this area and future studies should capture multiple pre-frailty domains along with global measures of frailty.*

Recommendation: *A two-step screening and assessment approach is an acceptable and accurate means to identify pre-frailty in a community setting, though more research is needed to confirm this.*

3.3 ICT Training Modules to Manage Pre-frailty

Three training modules were developed during the project, one for each of the three-domains targeted: (a) nutrition, (b) cognition and (c) physical function. This section outlines how each module was developed, the results of their implementation, the conclusions drawn by the PERSSILAA researchers and the recommendations made. This section also examines the importance of health literacy, which impacts on patient satisfaction and healthcare utilisation and costs among older adults [63]. It also includes a preliminary analysis of the effects of the training platform on participant's quality of life.

Nutrition Training Module

Nutrition is central in the development of frailty [62] and is especially important for older adults. Ageing is associated with increased risk of becoming malnourished [64] or undernourished i.e. at risk of malnutrition [65]. Although data varies considerably by setting and sample surveyed, it is estimated that between 10–35% of community dwelling older adults are at risk with prevalence rates in acute hospitals approaching 45% [66]. Up to 65% of residents in long-term care are reported to be at risk of malnutrition [67]. The cause is often inappropriate food consumption [68], manifest by a gap between actual nutrient consumption and recommended dietary intake. Education on healthy eating and nutrition is therefore crucial to provide adequate and reliable information to consumers and healthcare providers to promote healthy diets in all settings. The NUTRIAGEING website (http://nutriageing.fc.ul.pt/) is an easy-to-use, "app-like" interface designed to promote and translate scientific knowledge into usable person-centred nutritional advice for the general public. It's three areas are: (1) Healthy eating, (2) Recipes and videos, and (3) Vegetable gardens. The "Recipes and videos" subsection includes 15 videos of recipes developed by the Portuguese Chef Hélio Loureiro. The functionality of the website was tested with 45 older adults and their carers in two day care centres in Portugal. In feedback sessions most participants rated the site as excellent. Take home messages included the need to make websites connecting science and public health such as the NUTRIAGEING™ website: (1) easy to use, (2) evidence-based and (3) readily accessible (appealing and enjoyable format) to encourage access and learning.

Recommendation: *Nutritional education, required to promote healthier eating habits among the general population and in particular pre-frail older adults, can be delivered successfully online*.

Recommendation: *Educating caregivers on the benefits of nutrition using ICT-supported platforms such as the* NUTRIAGEING™ website *is important and may benefit older adults directly – more research is required to confirm this*.

Recommendation: *Educating cooks and professionals involved in food preparation on the benefits of healthy foods and nutrition using ICT supported platforms such as the* NUTRIAGEING™ website *is important and may benefit older adults directly – again, research is required to confirm this*.

Recommendation: *ICT platforms, if user friendly and intuitively designed, can support wider public health goals by providing the general population including older adults but also healthcare professionals with reliable information and easy-to-use tools, which may increase their knowledge of nutrition and healthy eating*.

Cognition Training Module

Demographic ageing is associated with an increased prevalence of cognitive impairment including mild cognitive impairment (i.e. subjective and objective cognitive deficits without impairment in ADL function) [69] and dementia (i.e. subjective and objective cognitive deficits with a clear impact upon ADL function) [70]. Recent data suggests that the incidence [71] and prevalence [72, 73] of dementia is reducing in developed countries, likely in response to higher levels of education and other socioeconomic factors such as diet and exercise which have improved cardiovascular and cerebrovascular health over recent generations [74]. Cognitive brain training has also been postulated to slow progression from prodromal stages of cognitive impairment to more advanced stages [75]. Further, studies examining multi-domain interventions directed to at risk population's show that cognitive stimulation combined with lifestyle modification (diet and exercise) and focused cardiovascular risk-factor management can reduce progression to dementia [33].

In PERSSILAA the mean AD8 score for the total sample of 4,071 participants screened at baseline was 0.66 ± 1.22 compared to 1.03 ± 1.28 for pre-frail older adults, (See Table 1). Frail participants approached a score of two or greater on this screen suggesting that these were more likely to screen positive for cognitive impairment [76], albeit the specificity of the AD8 at this cut-off is low [77]. The mean Q*mci* screen score of pre-frail participants, providing more detailed evaluation of specific cognitive domains at the face to face assessment, was 64.5/100 ± 11.32, within the accepted range of cut-off scores for separating mild cognitive impairment from normal cognition: between 64 and 70/100 [60] suggesting that many of these participants were manifesting early evidence of cognitive deficits in keeping with cognitive pre-frailty. The median and interquartile range of Q*mci* screen scores are presented in Table 2.

Table 2. Distribution of Quick Mild Cognitive Impairment (Q*mci*) screen scores including maximum score, median and interquartile range for pre-frail older adults including in second level assessment.

Subtest	Max score	Median	Interquartile range (Q3−Q1) = ±
Orientation	10	10	(10 − 10) ± 0
Registration	5	5	(5 − 5) ± 0
Clock drawing	15	15	(15 − 15) ± 0
Delayed recall	20	12	(16 − 12) ± 4
Verbal fluency	20	8	(11 − 5) ± 8
Logical memory	30	16	(18 − 12) ± 6
Total Q*mci* screen score	100	65	(72 − 58) ±14

During the course of the evaluation, pre-frail older adults were asked to complete the cognitive training modules over a period of 12 weeks, 3 times per week with each session lasting for an hour. The cognitive training tasks were selected from the Guttmann NeuroPersonalTrainer® and incorporated into the platform in two blocks: the first group (Block 1) were assessment-oriented tasks and the second group (Block 2) training-oriented tasks. Block 1 was composed of 10 different tasks, Block 2, 25 tasks. Both sets of tasks addressed the primary cognitive functions related to ADL. At the completion of each session, users received a score from 0 to a maximum of 100 points. The therapeutic range was set between 65%-85% of peak performance and difficulty levels were adjusted according to individual performance. Cognitive training was trialled in both evaluation sites. In Enschede (Netherlands) 18 older adults participated individually completing a total of 893 tasks during 107 sessions. In Campania (Italy) 53 participated in 15 collective (group) sessions: a total of 223 individual log in's to the trainer. Usability testing showed that most participants who were evaluated, eight participants in the Netherlands and ten in Italy, were satisfied. The average satisfaction score across the two sites using the system usability scale (SUS), a subjective 10-item Likert scale measuring usability [78], was 64/100 supporting the usability of the cognitive training module. Interview sessions were also completed with users who provided additional information on the format of the NeuroPersonalTrainer®. Based upon these results the following recommendations were made:

Recommendation: *Cognitive training tasks for use with pre-frail older adults should be easy to understand and use. Important information should be provided in a large, conspicuous, non-crowded format in the person's central visual field.*

Recommendation: *The visual display on cognitive training devices for pre-frail older adults should be simple; avoiding distracting visual stimuli (such as elaborate backgrounds and flashing or flickering lights) unless they are used judiciously to signal a specific required action or function.*

Recommendation: *Clear instructions should be provided to pre-frail older adults before each cognitive training task, particularly where additional effort is required on behalf of the end user (e.g. sustained attention tasks).*

Recommendation: *Immediate feedback should always be provided to pre-frail older adults after completing individual cognitive training activities. Aggregated information should also be provided to show trends or evolution in performance over time.*

Recommendation: *The difficulty of cognitive training tasks for pre-frail older adults should be tailored to each individual's level based upon normative data for these tasks.*

Recommendation: *Cognitive training modules for pre-frail older people should be adapted to mobile/smart technologies and devices. Engagement with training should be encouraged with techniques such as gamification or through the use of group work (either remotely or at centralised locations).*

Recommendation: *Fields that represent pre-frail older adults' interests or hobbies should be used throughout cognitive tasks (in the form of images, texts, words etc.) to personalise the experience for older adults.*

Physical Training Module

Frailty and pre-frailty are associated with a defined frailty phenotype characterised by Fried's criteria which includes symptoms of weakness, exhaustion, reduced physical activity and slow walking speed [7]. Frailty is also associated with prodromal disease states such as sarcopenia, osteopenia and osteoporosis that contribute and exacerbate the impact of frailty related adverse outcomes such as falls and hip fractures [79]. Identifying early physical decline is therefore important to initiate interventions to prevent these events. Regular physical activity, particularly resistance exercises can slow the development of frailty [80]. Data also suggests that exercise interventions can improve ADL function among frail older adults and delay progression of functional impairment or disability, though which particular interventions offer the most benefit is unclear [81]. The Otago Exercise Programme (OEP), an established, validated, cost-effective home-based tailored falls prevention programme [82], reduces the risk of falls and mortality among older community dwellers [83], though it is unknown whether it can be used remotely by pre-frail older patients. A technology-supported self-management, physical training module platform, based on the OEP, was developed for use on the PERSSILAA platform, structured around an existing system called the Condition Coach (CoCo) [84], containing advice and instructional videos, which were adapted for use with pre-frail older adults through an iterative design approach [85]. Participants using the physical training module were asked to log in and train online three times a week over three months. Data showed that there were high levels of compliance and tolerance with the programme. Of the participants finishing the complete protocol (i.e. 12 weeks of training), the majority continued using the service for up to one year. High levels of satisfaction were reported, an average score of 84/100 on the SUS. In the mcRCT average Chair Stand Test and Two minutes step test scores increased for those using the physical training model compared to controls, though this did not reach statistical significance.

Recommendation: *Strategies to motivate pre-frail older adults to begin and to continue using physical training modules on ICT supported platforms should be included as part of the implementation process.*

Recommendation: *A 'home' online physical training module provided on an ICT supported platform is feasible for pre-frail older adults, though professional support seems useful and should be provided as back up.*

Recommendation: *The provision of physical training modules on ICT supported platforms to pre-frail older adults, at risk of frailty or functional decline may enable them to improve their physical fitness, though more evidence is required.*

Health and ICT Literacy

Older adults now represent the fastest growing section of society [1] and are biggest users of healthcare. Despite this, insufficient attention is paid to their understanding of health literature and few measures have been put in place to improve this [86]. PERSSILAA identified this as one of the biggest challenges in introducing ICT-supported screening, triage and management strategies. It is known that simple measures can rapidly improve older person's understanding [87] and this is also applicable to eHealth literacy skills [88]. To overcome these difficulties, health and ICT literacy programmes were developed in Italy, utilising a 'Train the Trainer' approach with healthcare professionals and local volunteers teaching older adults as part of the PERSSILAA response. In total, 2,560 older adults attended ICT training, with a median of 14 people attending per lesson. Feedback was excellent with older adults reporting that they would not have been able to interact with the training and monitoring modules without it (see Sect. 3.5).

3.4 Effects on Quality of Life

Frailty [89] and its subdomains including nutritional and physical impairment are associated with reduced quality of life in older adults [90, 91]. As part of the planning for the PERSSILAA project a survey conducted with participants suggested pre-existing high levels of loneliness and depressive symptoms. In all, 73% reported feeling empty and 74% mow mood or depressive symptoms. To explore this further, the European Quality of Life–5 Dimensions questionnaire (Euroqol EQ-5D), scored from 0 (worst imaginable health state) to 100 (best imaginable health state), was used to measure the effects of the PERSSILAA training modules on participants' quality of life. This was also included to facilitate an economic analysis of the cost effectiveness of the project. The EQ-5D was measured at baseline and end-point for those participating in the mcRCT. The final mean score increased compared with the initial assessment by a mean of 10 points suggesting that those using PERSSILAA reported a higher quality of life after using the platform. The Short-Form 12 (SF-12), which includes both physical and mental domains taken from the more comprehensive SF-36 was used to measure perceived health. Higher scores were found on the Mental Component Survey of the SF-12 for those using PERSSILAA training services compared to the control group, suggesting that better mental health is associated with the use of the platform. Based on this, we concluded that participation with the project design improved perceived quality of life. This would be expected given that several components of the PERSSILAA training modules such as exercise [92] and nutrition [93] are known to improve participant motivation, mood and quality of life.

Recommendation: *Engaging in online multi-domain training modules to manage pre-frailty may improve the perceived quality of life of older adults.*

3.5 Monitoring for the Development of Frailty – Frailty Transitions

Frailty is increasingly being recognised as a dynamic syndrome where individuals may transition through different trajectories from frail to pre-frail or robust [17]. The evidence however suggests that this is usually unidirectional with few older adults transitioning from frail to pre-frail or robust when followed in longitudinal studies [17]. However, these have been limited by the type of data available, which relies on face to face assessment. While technology can provide unobtrusive monitoring, it may also distract end-users and lead to 'attention theft', necessitating a more non-invasive approach in the home environment, particularly when daily activities are being measured [94]. Further, while useful with younger adults, it is unclear if such models are applicable to pre-frail or frail older participants. While older adults do engage with ICT, its uptake is low [95]. Further, it is challenging to combine all the information collected in a meaningful way in order to obtain an overview of the everyday functioning of pre-frail older adults. Different approaches to monitoring were used in PERSSILAA to overcome these challenges depending on the pre-frailty domain assessed. To facilitate monitoring, software was provided on the portal, and on mobile and home sensing devices. All data were collected automatically and uploaded into the PERSSILAA database for analysis. The following approach was taken: transitions between different frailty states (robust, pre-frail and frail) were examined using the GFI data at baseline and end-point. Nutrition was monitored using two questionnaires to evaluate eating habits: the 24-h dietary recall and an additional 'general' questionnaire developed by the PERSSILAA investigators. To supplement this, a 'smart scale' (weighing scale connected wirelessly to a computer application) was used to monitor participant's weight on a daily basis. For cognition a shorter version of the full Guttmann NeuroPersonalTrainer® was developed to enable monitoring of cognitive function over time in short sessions of less than 15 min comparing each score with baseline and the previous results. For physical function a step counter was chosen to monitor daily physical activity and obtain an overview of physical functioning, all collected by means of a smartphone application. Wellbeing was also measured daily using a smartphone application recorded. The acceptability of the monitoring module was evaluated through semi-structured interviews and by measuring how frequently the technology was used over one month of follow-up.

In all, 169 participants had completed the GFI at baseline and end-point, of whom 78% remained robust, while half remained stable: pre-frail or frail. One quarter transitioned from frail to pre-frail and from pre-frail to robust. One fifth converted from pre-frailty to established frailty (See Fig. 2). The proportion transitioning is higher than that reported previously and likely represents differences in the way that data is collected and a shorter period of follow-up. There was no statistically significant difference in overall ‘global’ frailty status as measured by the GFI between those included in the mcRCT as cases utilising the PERSSILAA training modules and pre-frail controls, $p > 0.05$. In addition, 12 participants took part in the monitoring feasibility sub-study. Each completed a survey at baseline to understand their usual self-reported familiarity and ease with using ICT. These were then followed for one month with daily weights (‘smart scale’) and a pedometer to assess fluctuations in weight and physical activity. Overall, the compliance of participants was modest suggesting that ICT monitoring devices should be carefully designed to meet their requirements. Most participants stated that they understood the importance of a healthy diet and physical exercise for their overall health.

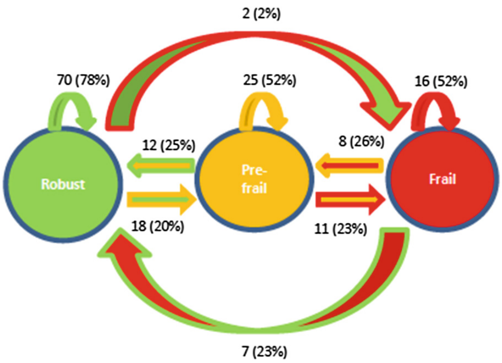

Fig. 2. Frailty transitions (n = 169) for participants with baseline and end-point Groningen Frailty Indicator scores between 2014–16 [61].

It was also found that most participants enjoyed the ‘brain training’ games but preferred not to be confronted or compared with the results of peers. Overall, the results of the continuous ICT monitoring showed mixed results and showed that while open to new technology to improve their health, it must meet their needs and expectations. Thus, further research is required to examine the benefits of continuous monitoring. Striking the balance between non-invasive monitoring that is non-obtrusive and avoids ‘attention theft’ and more obvious strategies that increase awareness and encourage use of ICT are needed to gain wider acceptance among this target group.

Recommendation: *There is likely to be no ‘one-size-fits-all’ approach to monitoring older community dwellers for pre-frailty. However, ICT training is required for older adults in order for them to engage with monitoring, particularly where end-user feedback is required.*

Recommendation: *Monitoring of everyday function must be complemented by meaningful (older adult-specific) information to support the adoption of healthier behaviours.*

Recommendation: *Technology to support the prevention of functional decline must go beyond the disease oriented-perspective and focus, instead, on strategies to maintain independence in daily activities.*

Recommendation: *When remotely monitoring older adults′ health (pre-frailty) status using ICT technologies, systems should provide feedback on the data collected.*

4 Conclusions

This work describes the healthcare findings of the three-year, FP7-funded, PERSSILAA project, highlighting the potential of a multi-domain, ICT-based service module employing gamification techniques in targeting pre-frail older adults living in the community at risk of becoming frail and developing functional decline. The results of the project are discussed in terms of the healthcare recommendations that can be drawn from the project that could be used to support the development of European guidelines on managing pre-frailty. This is much needed as frailty represents an important emerging public health challenge for the EU [96]. To date, interventions have been predominantly reactionary in response to manifest frailty or confined to limited evidence-based, clinical approaches to manage frailty including exercise training and nutritional supplementation [97]. Giving the increasing numbers of older adults in the EU [1], there is now recognition that preventative approaches are urgently required [96] and interest has focused on the ability of technology to support early detection and monitoring of those at greatest risk [43].

The results of PERSSILAA demonstrate both the acceptability and feasibility of deploying an integrated ICT-based platform for use by with older adults, who traditionally find the use of such technology difficult [98], especially where they have coexisting physical or cognitive impairment [99, 100]. As far as we are aware, this is the first study to examine the experience of using ICT among older, pre-frail, community dwellers. The results show that these rated all three training modules (nutritional, cognitive and physical) high for usability. Further, results were consistent for the two disparate populations sampled: older Dutch community-dwelling adults attending general practice (their family doctor) and older Italians living in communities centred on their local church. Although only older Portuguese individuals assessed the NUTRIAGEING™ website, it unlikely that their views differ considerably from the other participants in Italy or the Netherlands.

In total, PERSSILAA screened over four thousand community-dwellers and showed the feasibility of employing multi-modal screening approaches including postal and online questionnaires and targeted approaches through primary care to identify suitable participants in such studies. The screening approach using validated short frailty and domain-specific instruments shows the potential of and necessity for a two-step screening and assessment approach in order to identify suitable participants. This was important and is consistent with evidence that two-step screening is preferable [50]. It also supports evidence that primary care is a suitable target to identify community-dwellers at risk of developing frailty and an appropriate location for the implementation of such approaches [101]. The study demonstrated clear frailty transitions over the course of the project with only small numbers (2%) transitioning from robust to frail during follow-up. Reversibility was also seen with one quarter of frail and pre-frail individuals transitioning to a lower frailty status.

eHealth interventions offer the option for older people to assess both information and therapeutic strategies while networking with peers and healthcare professionals [102]. Despite this, few studies have incorporated eHealth literacy interventions into studies evaluating health outcomes. Another important result from PERSSILAA is that health literacy and ICT (eHealth) literacy are useful in supporting older people to access such services. Older Italians taking part in PERSSILAA felt they benefited most from the social environment created by the classrooms provided. In contrast to this, Dutch participants preferred to train alone and preferred not compare results with their peers. This likely reflects different cultural backgrounds and suggests that a one size fits all approach is unlikely to be successful when integrating ICT into the everyday lives of older Europeans to improve their health status. Gamification is now increasingly recognised as an important strategy to motivate behaviour change and has shown the potential to significantly increase adherence and improve healthcare outcomes [46]. PERSSILAA is also one of the first studies to study the effects of gamification [43] on older adults and how it may help engage them with ICT training modules.

The results also highlight many of the challenges and limitations of undertaking similar studies, particularly the difficulty of sampling an ill-defined population: pre-frail, older adults, who while at risk for subsequent frailty and functional decline may not be aware of this or motivated enough to engage with screening processes. While, the two-stage process enhanced the screening pathway, it is possible that some participants may have been misclassified as no gold-standard independent assessment was performed e.g. by a consultant geriatrician. This is a recognised limitation of such work where the application of screening tests or frailty scales cannot be considered an equivalent [103]. However, several of the screens used have excellent sensitivity though relatively poor specificity meaning that a face-to-face assessment was required to ensure that participants were pre-frail. The results did suggest that this strategy had reasonable accuracy in correctly classifying participants. Another limitation of the project is that due to restricted resources not all those screening positive for pre-frailty had a repeat assessment at the end-point of the study and only a small number were monitored. This limited the ability of the study to demonstrate frailty transitions. Hence, during the evaluation period the results presented may not be representative of the true trajectory of frailty in this population. Such proportionally high (approx. 20%) transitions from one frailty state to another over a short period are in contrast with data presented elsewhere in larger samples over longer periods [17]. Therefore, it is likely that this reflects the limitations of the screening and assessment process itself, delivered both remotely and face-to-face using validated instruments. This said, PERSSILAA aimed to show the potential for self-screening or screening by lay persons, something that is likely to become more widely accepted as healthcare becomes more proactive and less reactive, stepping away from the traditional medical model. Another limitation is that only a small sample trialled the full platform, released in stages as it was developed, which meant that no significant impact upon GFI scores were seen. This limits the project to the development and evaluation of a service platform, which was the main focus of the research. Thus, as a proof of concept PERSSILAA shows the potential to use a multi-domain ICT-based platform with older, pre-frail adults.

In summary, this work presents an overview of 25 healthcare-related recommendations arising from the PERSSILAA project. The study provides the first practical guidance on how to develop and evaluate a novel ICT supported service to identify, assess, manage and then monitor pre-frailty to slow or prevent the emergence of established frailty and associated functional decline, showing the potential for an ICT platform targeting key pre-frailty domains: nutrition, cognition and physical function. The results of this evaluation are being analysed further and future research is being planned to validate the PERSSILAA platform with a suitably powered RCT to determine if ICT-supported services can prevent or delay onset of frailty and functional decline in pre-frail community-dwelling older adults.

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Pervasive Business Intelligence in Misericordias – A Portuguese Case Study

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Abstract. The healthcare system is one of the main pillars of any society. However, it carries with it an enormous economic weight. Portugal, alongside with many others, is a country in economic and social restructuration and consequently, the need to increase the efficiency of resource management and services is imperative. With the proven effectiveness of Business Intelligence (BI) in many organisations, the urge to implement such tools in Healthcare arises, specifically in the healthcare of Misericórdia. In addition to the results, it presents a critical analysis of the implementation and the process followed for the development and usage of KPIs. In this work, some concepts associated with the use of BI in Misericórdias were addressed, and the architecture of the developed solution was designed. It is also important to emphasise that the solution presented is pervasive, available anywhere at any time. Through this work, it was possible to gather all the data into a single structure (Data Mart), to identify a set of aspects that can be improved and to have a generalised view of the state of operation of the organisation, as far as health care is concerned. The developed includes ten KPIs in the area of Surgery Production and Waiting List Surgery. The dashboards can be analysed in several dimensions: date, specialities, physicians, service, diagnosis, location and time.

Keywords: Business intelligence · Misericórdia · Data mart
Pervasive HealthCare · Dashboards

1 Introduction

Due to political decisions, the number of Portuguese *Misericordias*, in the last few years, have been increasing. These Institutions are a non-profit organisation that can provide local and specific care to the patients. Non-profits have always been present in society, playing a critical role in it. Misericordias are responsible of offering services in a few number of specialties, providing a new type of care outside the main hospitals. However, existing information systems are not prepared for these type of institutions, and a solution is needed. After a first overview, the main need is Business Intelligence.

Consequently, a case study was created to develop a pervasive functional prototype of BI focused in the Misericordia needs. This prototype aims to increase the efficiency and effectiveness of the care delivery.

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One of the purposes of this paper is to present the results obtained and following advantages and disadvantages of applying a BI platform in the health area of an organisation, to understand the extent to which a sustained decision-making process is important in an organisation. This paper represents an extension of a paper previously published about the introduction of BI in Portuguese Misericórdias [15].

This work is divided into several sections. A brief introduction is initially exposed. Next, in Sect. 2 a background is presented to introduce the background in which the article is found. Then in Sect. 3 is stated the methodologies used to develop the Pervasive BI platform. In Sect. 4 is presented the case study with a particular focus on the steps and BI architecture. Section 5 presents the main achieved results. Section 6 address a short discussion of the results and final, in Sect. 7 conclusion and future work.

2 Background

This work aims to contribute in the improvement of the healthcare due to its globality, i.e., it affects every citizen. The quality of healthcare delivery has a vital role in modern societies. Thus, the need for a more sustainable decision-making process arises, as well as the need to identify possible aspects to be improved. An informatization process of healthcare delivery involves the optimization of clinical procedures, with a changeover of paper-based records to electronic processes.

A correct clinical diagnosis is based on the analysis and monitoring of the clinical information of each patient. This data can be converted into knowledge able to improve the decision-making process. Nowadays, with the technological and economic advances, all this clinical information is available and distributed by different Information Systems (ISs). According to Marins [3], hospital information systems (SIH) are "systems responsible for acquiring, processing and presenting all information about all the participants (patients, doctors, nurses, among others) and all services, among others)".

This reality brings extra responsibilities to organisations. They need to manage their workflows better, and their decision process should be sustained by a Business Intelligence (BI) component. Organizations needs to make quick and efficient decisions in any of the business areas, being them tactical, strategic or operational, and this is one of the critical success factors. A correct decision-making from the organisational point of view is based on a large amount of data that allows them to perceive the best option.

As previous stated [15], *Misericórdias* are characterized as non-profit institutions, whose purpose is to express the moral duty of solidarity and justice [4]. Also, they play a considerable role in Portuguese society, characterised by the wide range of areas in which they work, with emphasis on health. During the analysis phase, it was concluded that the necessity of having a clear basis for decision-making is imperative.

Having in consideration the Misericórdias nature, non-profit organisations and the essential needs of providing better care to the citizens, a research question was formulated "How can the use of Business Intelligence contribute to decision making in a Misericórdia?". To answering this question, a BI prototype was developed after exploring open-source tools [13].

The following subsection presents the main topics addressed in this paper [15].

2.1 Portuguese Misericórdias

The *Misericórdias* have always played a significant role in Portuguese society.

According to the Decree-Law 172-A/2014 of 14 November the Ministry of Solidarity, Employment and Social Security, *Misericórdias* are "associations recognised in canon law, to meet social needs and acts of Catholic worship, by its traditional spirit, informed by the principles of doctrine and Christian morality". Although they have performed different roles in society, they have always been associated with the provision of health care [1]. According to the Decree-Law 172-A/2014, *Misericórdias* may provide goods and develop social intervention activities, which includes the area of health. *Misericórdias* can promote health, disease prevention and care in curative perspective, rehabilitation and reintegration. Also, Penteado [5] defines *Misericórdias* as associations of believers who, according to the country's legislation, have the status of IPSS, which was granted to them in 1979. The same author, Penteado [5], states that *Misericórdias* are non-profit institutions, whose purpose is to express the moral duty of solidarity and justice between individuals and the provision of services in the field of social security.

In Decree-Law no. 138/13 of October 9 of the Ministry of Health, these institutions play a major role in the health system, is increasingly recognized in Portuguese society. The same decree (Decree-Law no. 138/13 of October 9 of the Ministry of Health, 2013) states that the Misericórdias have been associated with the provision of health care, although they have different roles in society [6].

2.2 Pervasive Business Intelligence

In health, the access and presentation of medical information is identified as a major concern for health professionals. This concern is because caregivers need to make sustained and swift decisions because the patient's health is at stake. Currently, one of the biggest problems in health facilities is that all medical information is dispersed by several data sources, the result of the use of various tools. In this way, accessing, crossing and querying the data when necessary becomes a complicated task to perform promptly, which may lead to incorrect decisions from the professionals. To solve this problem, the need to use a pervasive system arises.

The main objective of a pervasive system in health is to achieve a quality care service, to anyone and at any time, regardless of their location or position [7].

A pervasive health system is characterised by a set of unrelated information, a set of stakeholders, and ubiquitous computing that connects digital infrastructures to our daily lives. It gathers, processes and distributes "any kind" of personal information and contextual data anywhere [7].

Pervasive Healthcare is considered a key factor in the reduction of expenses and is known for allowing improvements in disease management and advances in communication technologies and wireless networks providing the acquisition, transmission and treatment of critical medical information in real time [7, 17].

For Larburu et al. [8], the Pervasive Healthcare systems apply information and communication technologies to allow the use of omnipresent clinical data by authorised medical personnel.

Pervasive Business Intelligence (BI) systems in an area whose goal is to support decision-making by professionals.

2.3 Key Performance Indicators

Key Performance Indicators (KPI) are measures that allow monitoring the performance in the main areas of the organisational/business activities that are critical to success. The development of KPIs should form the basis of the analysis of the current performance of the organisation, its future requirements and the improvement strategies necessary for its success. Some principles should be considered for KPIs:

- KPIs should not be regarded as an end in themselves, but rather as a means of assisting management activities. They should foster informed debate leading to the definition of a continuous improvement plan;
- Their semantics are more related to the context of the organisation where they are inserted and should be used to make temporal comparative analyses (evolution over the time coordinate) rather than between organisations;
- The set of KPIs must be balanced. For example, efficiency measures should be counterbalanced by measures of effectiveness and measures of quality and user perception;
- Following their definition and approval, KPIs should be reviewed and updated. The review determines the usefulness for the management associated with each indicator and the reliability of the data source to ensure continuity in its use;
- The description of intended performance, which is measurable through KPIs, should be implemented at the organisational level that has sufficient authority and knowledge to ensure that the most appropriate actions are taken.

Initial proposals for KPIs will, of course, be imperfect. However, it is important that the organisation understands and applies the most appropriate KPIs to accumulate experience and knowhow.

2.4 Related Work

This article is an extension of a paper earlier presented [14, 15] and the previous work developed in two Master dissertations [9, 12]. The former work explored the viability of establishing a BI work in this area. For this aspect, the process-oriented potentialities, such as Business Process Management (BPM), Mlearn, and Balanced Scorecard, was used to precisely and objectively identify the information necessary to support decision making.

So, in the past work, some concepts associated with the use of BI in Misericórdias were addressed, and the Pervasive BI architecture of the developed solution was designed. The surgery area was the main focus, and the data stored in the various sources was extracted, processed and stored in one place. The data can be easily manipulated according to the needs of Misericórdia. A previous paper [14] also addressed the Strengths, Weaknesses, Opportunities, Threats (SWOT) of the solution proposed and presented the fundamental concepts, tools used by Misericórdias and process architecture. This paper adds new value to the work done. The current work elucidates the modelling process, the definition of KPIs and the presentation of some new achieved results. The new findings are focused in a new area of analysis: waiting time in surgery lists.

3 Methodologies

For the protyle development, two methodologies were followed. The research methodology used was the Design Science Research (DSR). Kimball methodology was used as the practical component. This chapter describes methodologies features, their phases and their relationship. The DSR methodology is based on a set of principles, practices and procedures for conducting research, through the design and assessment of artefacts able to solve problems [10]. The main tasks of DSR are the identification of the problem and motivation; Definition of the objectives of the solution; Design and development; Demonstration and finally evaluation and communication [10].

Regarding Kimball's methodology, also known as the business dimensional life cycle, it was conceived in the mid-1980s by members of the Kimball group. This method has been used in projects related to Data Warehouse and Business Intelligence (DW/BI) in the various organisational areas [11].

The main phases of this methodology are project planning; Analysis of business requirements; Dimensional modelling and design of the technical architecture; Selection of tools; Design and development of the Staging Area and finally installation and start-up and maintenance and evolution. It should be noted that throughout the development of all these phases of the project, a project management is carried out simultaneously, aiming at monitoring the entire evolution of the solution, deadlines, duration and so on [11]. These methodologies are useful to develop a solution in a phased and rigorous way, without forgetting any phase.

In fact, the combination of both methodologies allowed an oriented correctly and rigorously project development.

In the first DSR phase, the problem was identified and described. This phase was fundamental to clarify some business issues and making a methodical planning of work development. Then, some possible solutions were designed and assessed. After analysing the possible solutions an artefact able of solving the problem was developed and implemented using Kimball methodology. The stakeholders followed all the phases.

The last phase was achieved through the written of some scientific papers and solution documentation.

4 Case Study

A set of nine steps was followed for developing and using KPIs, which is divided into four phases (Fig. 1): Begin, Development, Implementation, and Review.

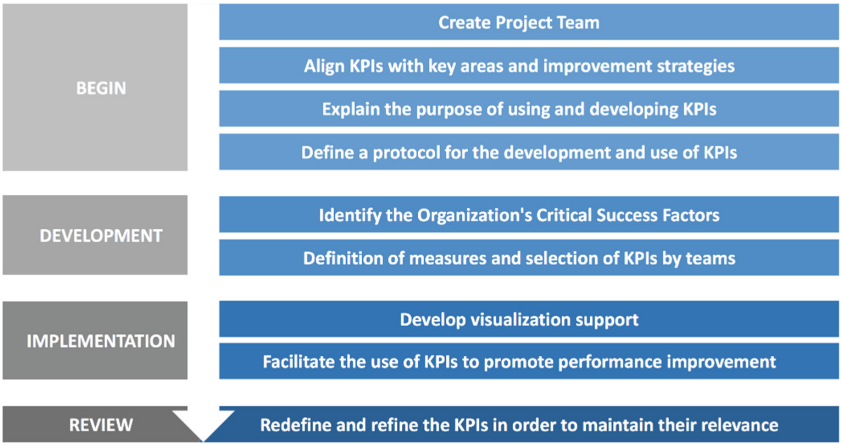

Fig. 1. Developing and implementation steps.

4.1 Phase I - Begin

Step 1 - Create the Project Team
It is proposed to create an inter-functional team to implement KPI measurement. This team should be composed of high-level stakeholders who are aware of the organisation's objectives and priorities. The team should also be familiar with the measure of performance. The number of team members will depend on the size of the organisation and can range from 4 to 6 elements.

Step 2 - Align KPIs with Key Areas and Improvement Strategies
There should be a strong correspondence between the key areas, the organisation's objectives to be achieved and the improvement strategies to be followed, as KPIs should be developed to support those strategies. The first step corresponds to the definition of the key areas and the respective objectives of the organisation, which are considered critical for the organisation and should be aligned with the KPIs that are intended to be developed. The objectives of the organisation may include:

- Improve user satisfaction;
- Improve resource management;
- Improve learning.

KPIs should be focused on simple ideas that represent key objectives with high relevance to the organisation regarding the project evaluated in order to ensure that the organisation understands the link between them and the business strategy.

Step 3 - Explain the Purpose of using and Developing KPIs
The purpose of measuring an organisation's performance is to assess how well the strategies and action plans are being implemented. You can only improve an organisation's performance if you can measure it first.

It is, therefore, necessary to develop KPIs, which will correspond to a set of indicators that will allow monitoring the performance of the main areas of "business" activities. KPIs are an important tool to support improvement in order to achieve organisational goals and prosperity globally. These can also create essential feedback and a learning mechanism to support management decisions.

The goal of using and developing KPIs should be disseminated within the organisation, from the bottom-up to the top, in order to make them aware of their own role in the perspective of getting involved and helping to achieve the objectives of the organisation, as well as the measurement of indicators and their improvement.

Step 4 - Define a Protocol for the Development and Use of KPIs
After the creation of the team, that will be responsible for the development of the KPIs, and defined the key objectives, which should be measured and therefore aligned with the KPIs, and communicated and disseminated the purposes of implementing the KPIs; a protocol should be established for their development and use.

This process should include:

- Definition of the duties of team members;
- For each one of the KPIs selected by the project team, a set of Input, Calculation, Output, and Progress procedures should be reported during the implementation phase as follows:
  – Input - involves all procedures for acquiring data and parameters used to evaluate KPIs;
  – Calculation - involves all the mechanisms and calculations required to determine the value of each KPI from the input data;
  – Output - evolves all processes and presentation of results (e.g., graphs, reports, gauges);
  – Progress - involves all requirements to monitor the evolution of KPI.

4.2 Phase II - Development

Step 5 - Identify the Organisation's Critical Success Factors
Critical Success Factors (CSF) are the core competencies or capabilities that must be fulfilled for the organisation to achieve its vision. In the current project, a CSF as been identified as:

Business goal	CSF
Improve patient satisfaction	Decrease waiting times for surgery

Step 6 - Definition of Measures and Selection of KPIs by Teams
Following the definition of the objectives of "Business" and CSF, a set of measures should be defined. These measures should specify the practical outcome that each organisation and project should achieve in accordance with the defined "Business Goals". They will also be useful in monitoring and evaluating the process leading to the achievement of these objectives. A possible set of measures may include:

CSF	Measures
Decrease waiting times for surgery	Decreasing waiting time for surgery

KPIs must have a set of characteristics that make them effective, such as:

- Restricted to a small number of strategically important objectives;
- Based on strategic objectives, making the more general in more specific;
- Consistent, in a balanced perspective, related to financial performance, satisfaction, efficiency and improvement;
- Straightforward and easy to understand by all those who will be evaluated;
- Associated with easy to acquire and calculate data;
- Dynamic (reviewed at least on an annual basis as part of the business plan as a way to ensure they reflect the priorities of the "business");
- Agreed, not imposed by management;
- Reported.

KPIs should not:

- Conflict with other measures without prioritising;
- Produce misleading information;
- Being or being seen as trivial;

All these characteristics must be considered in the development process of KPIs. The suggested KPIs, related to the respective measures, CSF and "business goals" are:

Measure	KPI
Decreasing waiting time for surgery	% surgeries performed within the maximum guaranteed response time defined by the Ministry of Health

4.3 Phase III - Implementation

Step 7 - Develop Visualization Support
In this phase, an architecture must be developed. In this case, the development of the Pervasive Business Intelligence (BI) prototyping component was based on an architecture composed of 3 levels, data sources, Data Mart and finally Dashboards and Reports. As can be seen in Fig. 2, two operational data sources and a set of tools were used to support the development of the whole process. The Misericordia defined this architecture and all the features associated with it.

In an initial phase data were extracted, transformed, loaded, and updated to Data Mart. Next, OLAP cubes were developed through access and manipulation of data and metrics created to meet the needs of users. Finally, panels with dashboards and reports were developed to present the data to the final user(s).

The entire process was developed using the tools shown in the architecture (Fig. 2): MySQL Workbench where Data Mart, Microsoft Visual Studio and Microsoft SQL Server Analysis Services are located where the metrics and OLAP cubes were

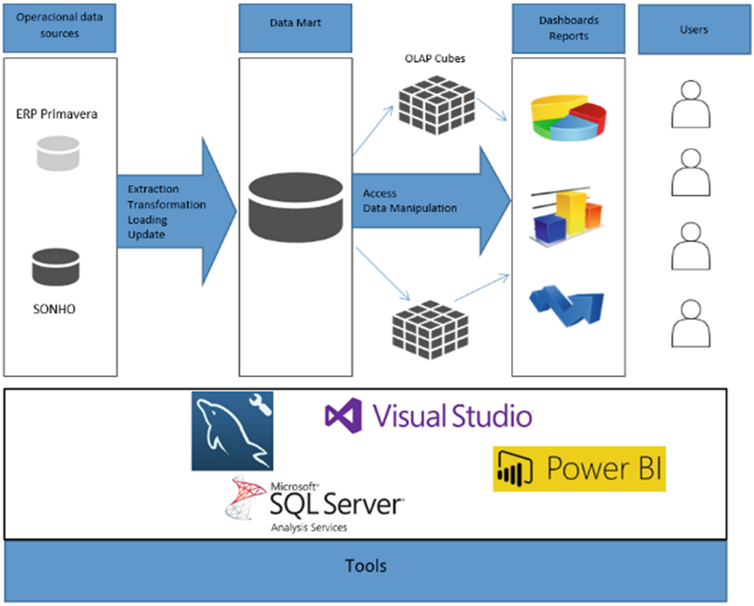

Fig. 2. Pervasive BI architecture [15].

developed and finally the Microsoft Power BI Desktop where the panels were developed and therefore presented the data. The fact that the data can be accessed in both the desktop and cloud tools indicates that it is a pervasive platform because the data can be queried and the panels changed if necessary anytime, anywhere.

The development of Data Mart was based on a constellation scheme designed per data type of the operational sources. This consists of two tables of facts, waiting days for surgery and surgeries production and eight dimensions in common (date, speciality, doctor, intervention, diagnosis, intervention type, users and responsible financial entities). Given the complexity of the scheme and to a better perception in the article, the scheme was divided into two diagrams: Waiting days till surgery (Fig. 3) and Production of surgeries (Fig. 4).

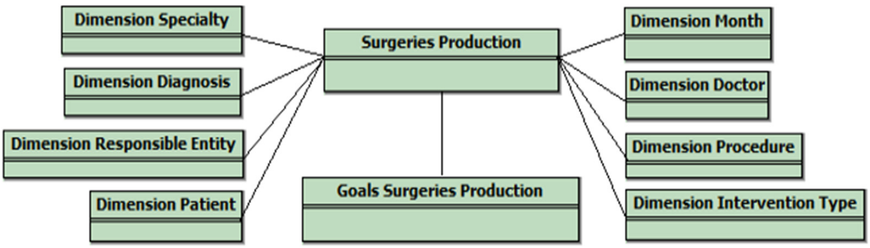

Fig. 3. Star schema for waiting days [15].

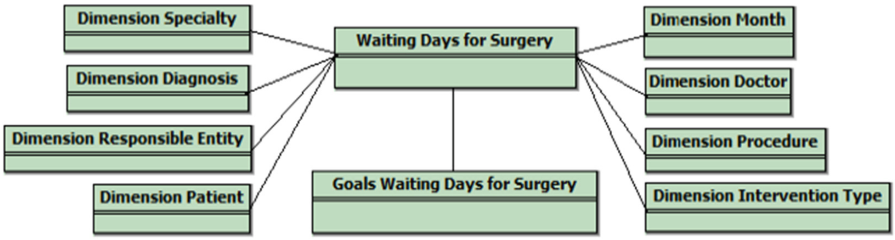

Fig. 4. Star schema for surgeries production [15].

The Data Mart is already deployed, and it is prepared to be used.

Now, it is the time to develop the KPIs. KPIs should be viewed and reported frequently. The trend of their values should be highlighted. Graphs with historical (previous) records are considered good practice.

The measurements obtained should be analysed and form the basis for the final report.

The multidimensional analysis using facts and dimensions of Data Mart allows a set of functionalities available to the user, among which:

- Ad-hoc creation and access to queries;
- Registration of queries for future use, which may be provided to one or more users;
- Performing Roll-up actions to aggregate the data from a more detailed perspective on a more generalised one;
- Selection detail level in the query, that is, allow the data to be explored for a more detailed perspective, performing drill-down;
- Definition the criteria of the data query;
- Show results of data analysis through graphs, tables and maps.

Over OLAP cube development were defined a set of metrics to allow greater analysis capacity in data presentation. Table 1 presents the developed metrics, where it is possible to verify which type of metric and what dimension or table of facts each metric is based on it.

Table 1. Metrics, types in each table [15].

Metrics	Type	Used table
Total surgeries	Record count	Fact table: waiting days for surgery
Maximum number of waiting days for surgery	Maximum	
Minimum number of waiting days for surgeries	Minimum	
Total surgeries production	Record count	Fact table: surgeries production
Quantity of patients	Record count	Dimension: Patients
Quantity of interventions	Record count	Dimension: Interventions
Quantity of doctors	Record count	Dimension: Doctors

Step 8 - Facilitate the Use of KPIs to Promote Performance Improvement Coaching makes it easier to use KPIs within the organisation. Employees must be motivated and committed to giving them a controlled authority and responsibility for improvement over the processes for which they are responsible. Managers should be encouraged to delegate responsibilities and employees to identify their own measures and seek solutions.

4.4 Phase IV - Review

Step 9 - Redefine and Refine the Kpis in Order to Maintain Their Relevance KPIs should be reviewed whenever the FSCs are examined. They should also be tested in terms of their relevance and adapted to any changes in the environment, processes and conditions.

Executives should be actively involved in reviewing measures and leading implementation efforts. Continuous communication, given the status and results of the evaluation system, is essential for the ongoing improvement of the system.

5 Results

The presentation of the data was done using panels in the PowerBI Desktop tool. Each group consists of a set of dashboards.

Figure 5 shows one of the presentations created.

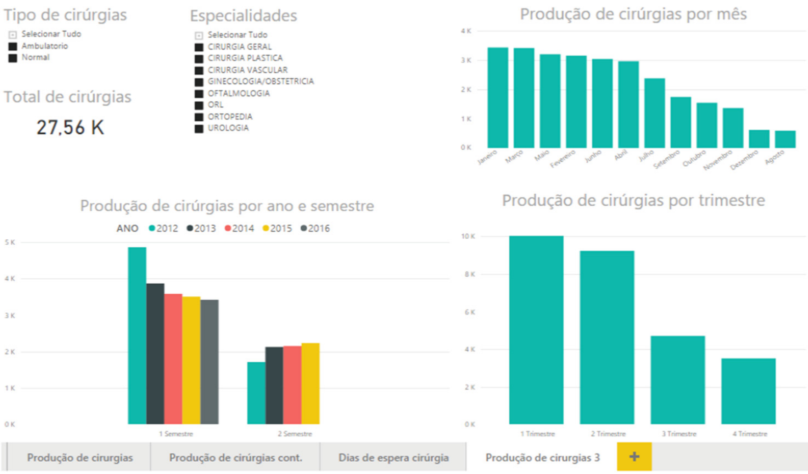

Fig. 5. Surgeries production panel example [15].

Figures 3 and 4 are two of the several examples of the use of the cube. As you can see in Fig. 5, it is possible to analyse the data with different levels of detail. In this case, it is feasible to analyse the production of surgeries by month (*mês*), a quarter (*trimester*), semester (*semester*) and year (*ano*), which allows obtaining knowledge regarding which periods of time the production of surgeries is more and less. In addition, it is possible to select only one or more specialties (*especialidades*) as well as the type of surgery (*tipo de cirúrgias*) that is intended, Ambulatory (*ambulatório*) and Normal (normal). This kind of information helps the manager to make decisions regarding, for example, what times of the year a larger/smaller amount of hospital material and a larger/smaller amount of health professionals are required. In this way, it is possible to tailor resources to hospital needs based on sustained decision making.

Figure 6 shows the number of patients waiting (*espera*). The number is 449. If the user checks *Operado*, it is possible to see the number of surgeries made. Both analyses can be filtered by physician, specialities (*especialidade*) and date. In this dashboard, you can see the waiting days (count, average and max) by specialities (*Dias de Espera por especialidade*) and the number of waiting patients and specialities (*Doentes em Espera por especialidade (número)*). This last dashboard also offers a visual distribution of waiting for patients by specialities.

Fig. 6. Surgeries waiting list panel example.

6 Discussion

This work showed the importance of Business Intelligence for Misericórdias. By using a BI solution, it is possible to influence the quality of life of each citizen directly. The decision-making process can be improved by the application of BI solutions. However, t is essential to design a roadmap for development and to know the business and their stakeholders to define a set of relevant KPIs.

In an health organisation, the volume of data is high and complex. Most of the time the information is stored in several sources which make it difficult to analyse it for later decision-making. This situation makes it an extremely complex process with a high degree of uncertainty [2]. Consequently, recognising the importance of decision-making in healthcare and the existence of BI solutions that facilitate the work of health professionals is an improvement for the organisation.

We addressed two subjects: surgeries and waiting time list. In both cases, the stakeholders can have visible benefits, being the patient the most benefited with the development of this prototype.

This work helps the physicians making better and more informed/data driven decisions and improves the surgeries waiting time. They can see the specialties that have the larger waiting time for surgery and which patients are waiting the longest. This tool is also valuable to assess the surgeries by area, diagnoses, physicians, date, place and many other possibilities. The work is now ready to meet the Critical Success Factor and to achieve the main business goal.

7 Conclusions and Future Work

With this work, the data stored in the various sources is extracted, processed and stored in one place and then easily manipulated according to the needs of Misericórdia.

The end user can easily access the dashboard in real time and make sustained decisions, which until then was a complex process.

The answer to the research question "How can the use of Business Intelligence contribute to decision-making in a Misericórdia?" is: BI can support the management of small process executed in the Misericordia. BI is an excellent tool to these types of institutions because it can improve the decision-making process by allowing a better control of the resources (humans, technical and financial) and surgery. The system can indicate the number of waiting patients and the patients who are waiting more time. By contributing to a profound understanding of the waiting times it aids the search for solutions and consequently its decrease and the increase of the patient satisfaction.

This architecture requires a complete system informatization, an interoperable system, and a full method of data storing and processing tasks. The transformation process can then convert the data stored into information/knowledge.

The system developed is ready to answer to user questions. The user can access the system and make some interactive queries. Then, the human can take a decision-based in the information received. The system is designed to providing new insights able to help the decision-maker (physicians or nurses) to make the right choices leading it to a positive impact on their patients. In brief, this BI solution can provide concrete information regarding the trends and needs of the *Misericórdia*.

The main contribution of this work is the full architecture of functional prototype, the KPIs design process and the solution implemented. This solution is pervasive and global because it can be optimized and adapted to other health facilities having the goal of improving the quality of healthcare and patient satisfaction.

This solution addresses a specific and critical field: the surgery. During this phase, Misericordia participated actively in the process, namely in requirements elicitation.

The project is in the installation phase. New dashboards in other areas will be developed and implemented after concluding the installation phase. The monitoring phase also will be implemented to measure the achievement of the business goal.

The assessment phase will follow the methodology already used in the Intensive Care Unit [16].

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SousChef: Improved Meal Recommender System for Portuguese Older Adults

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Abstract. Continuing efforts to increase the relevance and effectiveness of nutritional recommendations are essential to promote long-term biological effects. Several studies refer that older adults often struggle with making the right decisions regarding meal preparation, healthy diets or groceries shopping. In this work research on user needs are presented, where different stakeholders were listened concerning their needs and perspectives within the domain of nutrition in older adults. Moreover, an improved version of SousChef, a meal recommender system is here presented, where new heuristics were added to the system and the users can now choose between 4 to 6 meals to be planned per day. Since another important factor besides nutrition and food preferences impact food choice concerns with the budget, new heuristics were considered in order to reduce waste and shortening the shopping list. Also new heuristics were added to the system to better reflect the Portuguese nutritional guidelines and information about food prices in order foster reducing waste and shortening one's shopping list. The nutritional recommendations and the application was thought and designed for older adults, presenting friendly user interfaces and following the guidelines of a nutritionist.

Keywords: Recommender system · Nutrition · Intelligent companions Mobile health monitoring · Older adults · Personalized interfaces

1 Introduction

Although the exact definition of elderly age group is controversial, for high-resourced countries the World Health Organization have accepted the chronological age of 65 years as a definition of 'elderly' or older person [1]. The European Union population aged ≥ 65 years is estimated to rise by over 25% by 2035, and to 30% in 2060 [2, 3]. In Portugal, data from the last national statistics showed that population aged 65 years and older represents approximately 19% [4].

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An ageing population tends to have a higher prevalence of chronic diseases, physical disabilities, mental illnesses and other co-morbidities [5]. Thus, in order to promote long-term biological effects, continuing efforts to increase the relevance and effectiveness of nutritional recommendations are essential [6]. The health in older people is influenced by important modifiable factors, namely the nutritional status. The current economic crisis in some European countries, as Portugal, leads us to predict that the prevalence and consequences of the nutritional disorders will increase in the future years. Likewise, the Portuguese elderly population seem to have low nutrition knowledge as well as inadequate food habits, which is a challenge for the improvement of the nutritional status [3]. In fact, data on the food consumption of the Portuguese population, obtained through the National Food Survey 2015–2016 (IAN-AF) and the National Health Survey with Physical Examination (INSEF) showed that overweight is prevalent in the elderly; 4.8% of the elderly had a risk of malnutrition, 16.3% were hypo hydrated and 40% had a vitamin D deficit [7].

According to Madeira et al. [8], malnutrition status is influenced by multiple factors, including physical health problems (cachexia, sarcopenia, malabsorption or hyper metabolism), cognitive skills, appetite changes, mental health impairment (depression, alcohol abuse, among other), functional and/or financial autonomy, as well as socio-environmental context (social isolation, living in the community/residential homes, for instance). Several studies refer that older adults often struggle with making the right decisions regarding meal preparation, healthy diets or groceries shopping [9]. Studies also suggest that many older adults neglect nutrition and are more inclined to do so if they happen to live alone. Furthermore, under financial restrictions, which older adults often find themselves in, balancing healthy eating habits with money saving can become a complicated task [6, 10].

Taking into account the previous facts and acknowledging that nowadays technologies are always present and may be used to assist people, SousChef, a mobile meal recommender system to assist older adults by providing a nutrition companion to guide them into making wise decisions regarding food management and healthy eating habits has been presented in [11]. In the actual work we present the results of user research in order to better understand their needs that lead to the development of such a system and also describe improvements in the meal recommendation system based on the results of the previous work.

The present paper is organized as follows: Sect. 2 presents the related work regarding recommender systems and ICT applications related to food and nutrition; in Sect. 3, research on user needs is presented while in Sects. 4 and 5 the improved system and mobile application are described; finally, conclusions and future work are drawn in Sect. 6.

2 Related Work

2.1 Recommender Systems

Regarding mobile technologies related to food and nutrition, several studies may be found in the literature addressing issues such as: recommender systems [12–16], social interaction [17], menu generation [18] or cooking assistance for users with specific impairments. As this work presents a recommender system, we will briefly detail the related work in this topic.

In [19], the authors performed a survey of the state of the art on recommender systems and identified three main types of systems based on the employed methodologies: content-based, collaborative and hybrid recommender systems. The challenges related to the design and implementation of nutritional recommender systems are discussed in [13]. This author identifies the uncertainty of nutritional information of recipes or foods, or the missing or incorrect data from food recording measurements as the main challenges and suggests ways to tackle them. In [14] a literature review on Health Recommender Systems (HRS) is presented: studies have demonstrated that HRS have branched out in different fields of health industry and HRS applications have been increasingly embedded in the health service systems. Challenges and opportunities in HRS are also addressed in this paper.

In [12] the author has focused specifically on older adults and their nutritional needs, designing a recommender system with user interfaces designed to consider the specific needs of the user group. The recommendations generated by this system are based on parameters that go beyond nutritional needs, such as taste or available food items at the person's home. However, the description of the system says nothing about recipes prepared specifically by dieticians, it did not allow multiple users and it was not designed to accommodate specific medical conditions. Moreover, the user interface, given the time of that work, does not consider current mobile contexts of use.

In [15], a prototype for a healthy nutrition expert system for children is proposed that considers all stages of the child, their growth stage, gender and health status. A case study is presented and a web application was developed however, the validation of the knowledge for the proposed system is still needed. Recently, [16] presented NutElcare, a semantic recommender system that provides healthy diet plans for the older adults. It claims to retrieve reliable and complete information from expert sources as nutritionists, gerontologists as well as knowledge from information systems and nutritional databases and with that information aim to assist older people to take advantage of these tips and make their own diet plans.

2.2 ICT Applications

Regarding commercially available ICT applications designed for non-professionals, different options are available, such as Mealboard[1], Lifesum[2], Nutrino[3] and Shopwell[4].

Mealboard is designed to help users plan their meals, generate a grocery list and keep track of what is left in the pantry. This app allows the user to create a meal by moving meals from one day to another or adjust the number of servings. Once the meal plan is ready the app can generate the shopping list for that menu with a single tap from

[1] http://mealboard.com/.

[2] https://lifesum.com/.

[3] https://nutrino.co/.

[4] www.shopwell.com.

the user. A third interesting feature allows the user to keep track of what is in their pantry, once the shopping is done then the person can move and put the ingredients in the pantry. However, the Mealboard app do not take into account users' age or dietary preferences and the recipes used in the plan might not have been created or validated by nutritionists.

Lifesum guides its users on a journey to improving their wellbeing through diet strategies, exercise and advice, as well as providing options and tools to help users maintain a healthy lifestyle and achieve their own personal goals. It is the leading health and fitness app in Northern Europe, allowing the user to log what they eat every single day and proposes a breakdown of calories eaten and burned. The app includes a meal planning feature, which is a paid service.

Nutrino is a platform that provides personal meal planning according to the user profile, being its application available for both individuals and business. The app allows users to log data about their levels of exercise, water, food, sleep or stress and can be connected to activity tracking devices such as Fitbit.

Shopwell is another example of a personalized nutrition app that recommends foods to people based on their dietary needs and helps them to build healthy grocery lists. The app can help to match foods to the user's dietary needs, including avoided ingredients such as unwanted ingredients, added sugar, trans fat, and allergens like gluten and lactose. Moreover, it simplifies shopping for groceries by giving a score to the foods the user loves, based on the user's unique health needs. Shopwell is a Community Partner of the USDA and certified by Registered Dietitians and is available for both iOS and Android.

In general, among other features all of the above listed applications offer the ability to monitor calorie consumption based on the manual input of food from a database. Other features can be provided, such as step-by-step guidance to prepare meals, a shopping list, the use of social interactions through social networks and gamification. Among these applications, the last three are capable of creating personalized meals plan, however they are not designed to take into consideration elderly people nutrient intake recommendations.

3 Research on User Needs

In the initial stages of the project we begun to conduct user research with potential stakeholders of SousChef system in order to better understand their needs. The research focused on three main groups: nutritionists, food management providers, and of course, older adults. These interviews aimed to get different and diverse perspectives within the domain of nutrition in older adults. Individual semi-structured interviews were conducted with the nutritionists and food management providers and a focus group session was conducted with the seniors.

The insights accumulated during this stage are described in this section and constituted an important step to inform the design of the overall system, and in the definition of SousChef main features.

3.1 Nutritionists

The interviews with nutritionists aimed to explore the needs of nutritionists and their patients. We have looked into what kind of information nutritionists need to collect from patients in order to do their work and explored what does into the process of conceiving a nutritional plan.

Four semi-structured interviews were conducted. At the beginning of the interview, participants were asked to simulated an appointment and go through the steps and questions they would normally go through with a patient. Interviews were later transcribed verbatim and analyzed in order to identify the following major themes.

Collecting Eating History Data. Knowing in detail patients' eating habits is an important part in the diagnostic of seniors' nutritional state. Nutritionists want to find out what and how much the person is eating, in order to identify mistakes in their diets, and to learn more about the senior's food preferences. Whereas food tracking applications look for precise caloric intake, nutritionist use tools such the 24-h recall or a food diary, which are more tolerant in terms of data input. Besides being a tool to register ones' eating habits, food diaries serve to highlight the differences between what people say they are eating and what they are really eating. Moreover, the process of writing down everything one eats can help to raise awareness to ones' eating behaviors.

Changing Eating Habits. Regarding the issue of changing people's diet, it is important to stress out that nutritionists do not provide clients with a strict meal plan that tells them what to eat on each meal of the day. Instead, nutritionists provide their patients with general recommendations on how to eat healthier based on what they are already eating. Recommendations are personalized and adapted to each person's needs and preferences. All the nutritionists emphasized that it is important to work with the senior to come up with a plan that satisfies both parties. There is no point in suggesting seniors to eat something they do not like.

Moreover, the consensus among nutritionists is that dramatic changes should not be imposed to seniors' diets. The best strategy is to make small adjustments. We do not want to make them feel they lived all their lives eating incorrectly, thus the goal should be to identify the mistakes seniors are making and try to amend those mistakes.

Also, it is worth mentioning that rather than receiving a complete meal plan, patients receive from nutritionists a list of food suggestions for each meal of the day. With this approach, nutritionists provided the framework but seniors made their own decisions with regards to what to eat on each day of the week.

Explore More User-Friendly Portions. One of the hardest parts in the process of registering what people eat is to quantify how much one is eating. This task requires a person to look at the food and estimate how much there was in the plate before eating, and how much there is left. While recommendation systems such Souschef use grams as the unit of measurement to compute nutritional requirements, humans on the other hand require more tangible and visual measures. To facilitate the process of registering how much people eat and making food recommendations more comprehensible, nutritionists come up with more human-friendly units, such as spoons for liquids or rice, and using the palm of the hand as reference for 100 g of fish or meat. Therefore, an effective logging and recommendation system will also demand the conversion between grams and more human-friendly units.

Lack of Physical Activity. Nutritionists recognized that the lack of physical activity and the somehow sedentary lifestyle of seniors is a big barrier to their well-being. Overall, they all try to raise awareness to the importance of having an active life, and as part of their work, the interviewed nutritionists provide their patients with general recommendations regarding the practice of physical exercise. However, there is not seem to be a cohesive strategy with regards to the relationship between physical activity and nutrition.

Identify Key Moments to Introduce Water into Seniors' Diets. Dehydration is a serious problem among seniors given their decreased sense of thirst. In general seniors do not drink enough water so it is necessary to enquire about their daily water intake and to incentivize them to create better drinking habits. Contextual reminders and recommendation alternative drink are two common strategies to address dehydration issues. Contextual reminders take advantage of contextual cues in the environment to help people to drink water, for instance, drink a glass of water in the morning while taking the medication. Another strategy is to recommend people to replace water with other products that might be more pleasurable, e.g. tea.

Identity Interaction Between Drugs and Food. Identifying the potential problem that arises from the interaction of drugs with food will be crucial to any system that aims to handle people's diets. This topic is particularly important when addressing nutrition in older adults because seniors are usually poly-medicated and even nutritionists are not always aware of the contraindications of the active ingredient of a drug with food.

Food Recommendation Based on the Glycemic Index. Diabetic is quite common among older people, and it is a medical condition that imposes hard restrictions on a nutritional level. People with diabetes are required to control their sugar levels with the help of a glucose meter and adapt their eating according to their glycemic index. Controlling what, how much, and when to eat, is vital. People with diabetes are most likely already aware of the effects of food in their body, nevertheless, a reliable system must be responsive and adapt to the physiological state of each person. Consequently, any full-fledged food recommendation system needs to consider how to cater to people with such condition.

3.2 Food Service Management

The purpose of the interviews with workers from food providers was to better understand the decision-making process involved in the planning and managing of meals in elder care institutions. We aimed to identify problems and potentials areas for intervention in their current working process.

Five semi-structured in-context interviews with food service-related personnel were conducted. In these interviews, we talked with nine persons, where four were cooks and others were some type of manager or assistant. Hereby the main designs insights and opportunities are identified.

Weekly Basis Planning. Overall food stocks management works on a weekly basis, and until the end of each week orders are place with food suppliers to be delivered in the following week. With the exception of fresh products, staple ingredients, those use on a weekly basis, are bought in advance and in bulk. While menus are planned in advance, they need to be flexible enough to account for unforeseen situations, such as problems with food suppliers or donations.

Information Heuristics. The process of creating menus in the places that we visited is based on informal heuristics and the tacit experience of the people who work at the kitchen. The process is rather informal and derives a lot from the knowledge passed down between cooks. In most places menus weekly created weekly by the cooks, or by other personnel at the institution.

While the process of planning meals was quite informal, several heuristics, rules, or available resources constrain what goes into the decision-making process of creating a meal plan:

- Alternate between meat and fish on a daily basis.
- Do not repeat fish or meat on the same day.
- Alternate the garnish, e.g., do not serve rice two times in a row.
- Avoid repeating dishes from the last two weeks.
- Preparing food in advance.
- Special meals for holiday and special events, such as national and local holidays, religious festivities. Some religious customs compel people to follow a particular time of diet, e.g.
- Use dishes appropriated to each season. For instance, warmer meals are more comfortable in cold weather.
- Avoid fresh products on Monday, since it might be more difficult to get fresh products on Mondays.
- The diet dish should be similar to the normal dish, e.g. same ingredients but different cooking process. Such arrangement makes the logistic simple. The need for human resources and equipment is reduced since some steps are shared between dishes. Also, all seniors will be eating the same type of food, avoiding to draw attention to the fact they are eating diet food.
- Adapt dishes according to the human recourses available, e.g. a more labor intensive dish cannot be picked if there are workers on holiday.
- Health and safety guidelines must be followed when creating the meal plans. For instance, some foods cannot be served at some times of the year.

Menu Composition. Lunch and dinner followed same basic structure in the visited cafeterias, and overall consisted of a main dish, soup and dessert. Regarding the main dish, with a single exception, institutions offered a diet dish in alternative to the main dish. Diet dishes would have to be required by seniors, and often a medical prescription was required. Overall, the diet dish is very similar to the normal dish, but with a different cooking process or type of garnish. The advantage of such arrangement it is in the simpler logistics. The need for human resources and equipment is reduced since some steps are shared between dishes. Moreover, all seniors will be eating the same type of food, thus not picking out anyone because of their diet and avoiding the natural longings from seniors who cannot eat the normal dish. In addition to the main meals, institutions often offered morning and afternoon snack. These meals followed a more relaxed planning. That is, more or less the same products were served in all of these meals.

Dietary Restrictions. At their age, dietary restrictions are common, so cooks need to consider the individual needs of seniors in the planning of meals. While a different meal for each senior is impractical, variations of the same dish (e.g. fewer carbohydrates and more vegetables for diabetics) can be prepared. The documentation of dietary restrictions of seniors seems to be rather informal, and in some cases, it was only kept in the memory of the people at the institution.

Since dental problems are more common in older people, cafeterias had to consider special meals for these seniors. One common option is to offer a blend of the normal dish. With such strategy there is no need to cook different dishes, and only an additional step is required at the end of the cooking process. Another alternative mentioned is to serve baby food or porridges.

Cooking What Seniors Like. Cooking food that seniors are used to and like to eat was agreed to be essential for a good acceptance of food, and for a peaceful meal time. Tradition is an important part of the process of deciding what to cook. Seniors are used to eat traditional food, and those are the dishes they yearn the most. Likewise, they are usually not very keen on trying different ingredients and flavors. While institutions do not have formal procedures to collect feedback from seniors, they are typically quite vocal regarding what they like or do not like to eat. A significant part of planning meals comes from knowing the seniors and what they like to eat. Some of the cooks and technician have been with the same seniors for years, so already know what they like to eat.

3.3 Older Adults

In order to look into seniors' perspective with regards to healthy eating with conducted a group session with seniors, to understand the needs and issues they face when trying to have healthy eating habits, and how they deal with those same issues. We have approached this study with two main objectives in mind: (1) to identify barriers inhibiting seniors from developing healthier eating habits; (2) explore new ideas to promote healthier eating habits.

Two group sessions were conducted. In the first session about nine seniors participated in the conversation, although there were other seniors present in the room. Seven seniors participated in the second session. The results gathered in these sessions are described next.

Resisting to Temptations and Desires. The most predominant issue that seniors faced is what they describe as temptations or desires. Here we are not talking about urges to eat substantial meals, but rather desires to indulge in sweet treats or other kind of snacks. The lack of control is a main problem, since it takes a real effort to resist to the temptations that one goes through during a normal day. Seniors are well aware of their bad eating habits but eating is one of the few activities where they still have pleasure. At that point in life they want to indulge in something that gives them pleasure, even if is not the most sensible choice.

Out of Sight, Out of Mind. To deal with temptations and desires, the most common strategy used by seniors is what we can define as out of sight, out of mind. In order not to fall into temptation, they would simply refrain from buying tempting food. To put it simply, the approach used by seniors is to hide temptations from sights, and to limit in advance one's means to acquire those enticing products in the first place.

Aversion to Change. Seniors' aversion to change might be a potential problem to account for when trying to conceive diverse meal plans. Some seniors have quite rigid eating habits, and did not seem very keen to try new things.

Not Drinking Enough Water. While seniors seem to be well aware of the importance of drinking enough water, this is not something they do naturally. They are more than warned by their doctors to drink more often, drinking water requires a serious effort on their part. There is even some resistance to drinking water, and the winter seems to exacerbate the problem since they are less thirsty, and cold drinks are less enjoyable. To address the need of ingesting more fluids, one strategy is to drink warmer beverages such as tea and even coffee. Foods that have a large water content, such a soup, can also be used as an alternative to drinking plain water.

4 System Overview

In [11] the first prototype of SousChef, a meal recommender system for older adults was presented. In the referred work tests to the recommender system and mobile application were made with older adults, to infer, on the one hand, the adequacy and quality of the meal plans suggested and, on the other hand, to test the usability of the mobile application itself for this specific audience. In the next two sections we present an improved version of the system taking into account these results.

The SousChef system is composed of a central cloud server and a mobile application, the user interface for the system. The cloud server is responsible for centrally storing the information of the system and making it accessible through web service application programming interfaces (APIs). Its easy accessibility also facilitates the integration of information from other sources, which is demonstrated through the integration with Fitbit cloud services to retrieve users' activity measurements measured by Fitbit[5] devices.

The generation of recommendations can be triggered by the mobile devices through web service APIs and consider information from different sources: personal information provided using the user interface, activity data through Fitbit devices and nutritional information from the food composition database. Work performed on top this database will be described in the following subsection, followed by a detailed description of the recommender system.

[5] http://www.fitbit.com/eu/home.

4.1 Food and Recipe Database

The development of the SousChef system was based on the Portuguese Food Composition database elaborated by INSA [20]. This database contains the nutritional composition of over a thousand products (1094), including raw, cooked and processed ingredients and information about 42 nutrients. For calculation of nutrients in recipes, Euro Fir method was used [21]. The energy and salt values were calculated according Regulation (EU) N.° 1169/2011 of the European Parliament and of the Council of 25 October 2011. In this system context, a recipe does not refer to the instructions to prepare the meal, but rather to a combination of ingredients and respective quantities. Besides including food nutritional information, the LanguaL framework has been used to categorize food according to different criteria including its source, physical state, processing method.

The first task to prepare the database for the purpose of meal recommendations consisted in selecting the ingredients that were suited for the system, namely removing ingredients that are not suitable for direct consumption (e.g. raw chicken) and specific ingredients (e.g. salty chips) which are not considered healthy for the target group. Afterwards, and in order to ensure that SousChef's recommendations are not only suitable for every meal of the day and for the target population, but also culturally acceptable, combinations of recipes and ingredients were created. In the context of this system, a recipe does not refer to the instructions to prepare the meal, but rather to a combination of ingredients and respective quantities. It is worth noticing that the selection of ingredients and recipe creation were performed by a nutritionist.

Each meal of the day has been subdivided in meal divisions and combinations of ingredients have been created for each of those divisions. The recommendation for a meal will comprise a combination for each division. Table 1 shows how meals have been subdivided and how many recipes were created for each division. Each combination comprises the list of ingredients and respective quantities based on a daily intake of 2000 kcal.

The LanguaL descriptors have also been used to group food into product categories. Each product category represents products that need to be bought for different food. An example of a product category is pork spare ribs, which is what one needs to buy to cook grilled, stewed or boiled spare ribs. The price for each product category has been estimated so it can be considered in the recommendations.

4.2 Recommender System

The implemented recommender system follows a content-based approach and mainly employs information retrieval techniques [19]. The algorithm to create a personalized weekly meal plan has three main steps: calculation of nutritional requirements, selection of food items for each meal and scaling the meals to match the user's caloric needs (Fig. 1).

The Estimated Energy Requirement (EER) is calculated from the Institute of Medicine Equation [22] which considers person's characteristics (age, sex, weight, height) and a Physical Activity coefficient. The latest is calculated based on the Total Energy Expenditure measured using Fitbit devices.

Table 1. Meal of day divisions and respective number of created recipes.

Meal of day	Meal division	Number of recipes
Breakfast	Cereal	145
	Fruit	31
	Milk or milk derivate	10
Middle morning	Main dish	149
	Fruit	31
Lunch	Main dish	194
	Soup	18
	Dessert	38
Middle afternoon	Main dish	149
	Fruit	31
Dinner	Main dish	190
	Soup	18
	Dessert	38
After dinner	Main dish	149
	Fruit	31

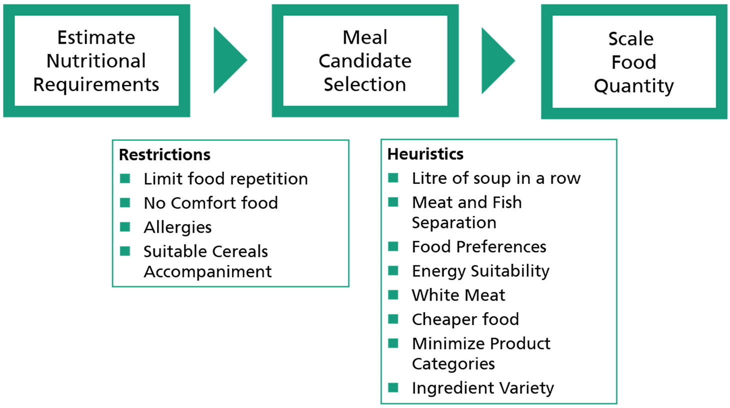

Fig. 1. Overview of SousChef meal recommendation algorithm.

The algorithm was designed in collaboration with a nutritionist and the applied heuristics followed the general WHO guidelines [6]. A summary of nutrient intake recommendations for older persons (age > 65) included in SousChef system are summarized in Table 2. Moreover, dietary recommendations using the “food-based dietary guideline approach” [23] were also taken into account.

According to the Portuguese Nutritionists Association, a person should eat five to six meals per day [24]. However, to allow a smoother transition of eating habits, SousChef is able to recommend between 4 and 6 daily meals. To do so, the system needs to be configured by a nutritionist, defining how the daily energy should be distributed across meals for each number of daily meals option.

Table 2. Summary of nutritional guidelines for healthy ageing [6].

Nutrient	Recommendation
Energy	1.4–1.8 multiples of the BMR to maintain body weight at different levels of physical activity
Protein	0.9–1.1 g/kg per day are beneficial for healthy older persons
Lipids	30% of the daily energy in sedentary older persons and 35% for active older persons; consumption of saturated fats should be minimized and not exceed 8% of energy
Carbohydrates	55 to 60% of the daily energy

After estimating the user's caloric needs, the next step consists in selecting the most appropriate ingredient combinations for each meal division considering the user personal context. The meal planning context consists of the user's personal information, including nutritional needs and food preferences, as well as meal planning history (in order to enable dietary diversity in the resulting plan). Considering the previously created combinations as candidates, for each meal of the week being planned, a two phase selection process will determine the most suitable candidate for that meal division. The first phase consists of applying restriction rules, which filters candidates that are not suitable for a given meal and context. Multiple rules have been implemented for removing candidates: limiting repeated recipes in the same week by removing candidates which have been used in planning more than twice; removing any candidates that include comfort food; filtering candidates that include ingredients users are allergic to; and excluding not suitable cereal accompaniments (cereals should be combined with milk or yoghurt, it should not be combined with e.g. coffee or sugar added milk).

The next phase consists in selecting the most suitable candidate from the ones that were not filtered. This is performed by calculating a score S for each candidate c according to different criteria reflected by heuristic functions Hn. Each heuristic function evaluates the meal planning context, which meal is being planned and each candidate to assign a suitability score between 0.0 and 1.0. Higher scores will be attributed to more suitable candidates according to the criteria reflected by the heuristic. Different heuristic functions have been implemented to reflect the criteria identified by the nutritionist. One of them consists in favouring main dish combinations with the same soup in four consecutive meals (about one litre). The idea behind this criterion is allowing users to cook soup once for several days. The heuristic function checks if the series of one litre was met. If so, the same value (0.5) is assigned to every candidate. Otherwise, 0 is assigned to candidates with a different soup and 1 to the others. Another criterion is to favour meat dishes for lunch and fish for dinner in order to have lighter dinners. For main dishes, the candidates meeting the criteria are assigned the score 1 and 0 to the others. All candidates for other meals are assigned 0.5. Users' food preferences are also considered. Using the application, users are able to provide ratings to ingredients from 1 to 3, which are normalized into a value between 0 and 1. The preference for a candidate is calculated by combining the preference for each of its composing ingredients whenever available or the value 0.5 instead. The energy suitability heuristic attributes higher preference to recipes whose energy value is closer to user energy requirements for a given meal. Another heuristic reflects a Portuguese nutritional guideline to include white meat in the diet, which tries to include recipes with white meat ingredients at least three times per week.

Other important factors besides nutrition and food preferences impact food choice, price is one of them [25]. Therefore it should also be considered by the recommendation engine, two heuristics have been implemented for this. The first gives preference to recipes with lower cost when compared to alternatives for the same meal division. The second tries to reduce the number of different product categories in the plan in order to foster reducing waste and shortening one's shopping list. For the same person, according to all previous heuristics, the same recipes would always be the optimal for each meal and the resulting plan would always be the same. To prevent this, an ingredient variety was implemented that attributes lower scores to recipes whose ingredients have already been planned. The score that is attributed is affected by temporal proximity, i.e. lower scores are attributed to food that have been used more recently than before.

The final score, S, for a candidate is calculated as the weighted average of the values calculated by each heuristic function and a respective weight representing its importance. The chosen candidate for each meal being planned is the one with the highest suitability score S. The approach followed by this algorithm benefits the scalability of the system, since it facilitates the inclusion of new restrictions and heuristics to consider new criteria and data to provide users with better recommendations. It also enables in the future to use different weights to each heuristic function for each user, personalizing the recommendations even further.

Once the ingredient combination has been chosen for each meal, the final step of the planning process consists in scaling the ingredient quantities in order to match the energy requirements of that particular individual. The previously calculated caloric requirements for a given meal are compared with the total energy of the ingredients in the chosen candidate's plan. If the difference is higher than an acceptable deviation, the quantity of the ingredients will be scaled to suit the requirements. To ensure that daily nutrient requirements are maintained, only ingredients from specific categories will be scaled: cereals, fruit and vegetables, dairy products, meat, fish, eggs and oil. The new quantity for each scalable ingredient is then calculated using a weighted average so the quantity of more caloric ingredients changes more than others, therefore reducing the changed amount in grams of the overall combination.

5 Mobile Application

The first prototype on nutrition, SousChef, is organized in three different components: the meal plan, the grocery list, and the activity monitoring.

To support these different components, there is a profile that aggregates the different settings and preferences which are used to refine the system. The profile contains anthropometric data, food-related preferences and activity profile. Regarding the food-related preferences, two levels of control are provided: food restrictions, and dietary considerations. While food restrictions are hard constraints, meaning that food added to the food restrictions list will not be returned in the meal recommendation, dietary considerations work with a similar principle, but only in a group level, restricting an entire set of products, and consist of a predefined list of diets that can be followed by the user.

In Fig. 2, the main dashboard of the application is shown and also some details about the profile area. In the top of the screen, the user can see different nutritional contextual tips, for information purposes. Also it should be noticed that the user can always change information regarding their weight or personal preferences in order to obtain meal recommendations more suited to his profile.

5.1 Meal Plan

The Meal Plan section is not only the central component of the entire system from a technical perspective but also from the point of view of the user. The Meal Plan fulfils two main goals: to generate new meal plans, and to track the user's food intake. In the application, the Meal Plan section is responsible for presenting all the information related to nutrition.

The Meal Plan (Fig. 3) is the place to record everything that the user eats throughout the day. There are two different ways to log information into the food diary: (1) Automatic food recommendations; (2) Manual input.

Automatic Food Recommendation. The fundamental feature of this system is the ability to generate personalized meals plan according to the needs of the user.

Manual Input. Considering that the recommendations generated by the system might not be enough to cover all the different scenarios involved in a typical diet, it is also possible to manually record additional information in the diary.

In addition to the food diary, which provides a quick overview of the user's diet, each recipe or ingredient has a dedicated view to display additional information and actions (Fig. 4). The nutritional information of a product is one of the aspects that are provided in this user interface. Besides the energy value in calories, there is also the macro and micro nutrients information.

Basic mechanisms for editing the product and the diary (for example, removing products from the diary) are also provided. The user is able to control the recommender engine by removing ingredients from the list of approved products and also to replace the meal that was initially suggested. However, the control level is rather limited since users are only able to make binary decisions.

In order to empower the user with additional control of the system, another feature particularly important in terms of personalization is the ability to personally rate the products both recipes and ingredients. Whereas in the former case the system works with hard constraints that remove products from the recommender engine entirely, in the latter case the user input is used to influence the weight of a product in the engine. The rating system used in this evaluation contains three different values, which are used to adjust the weight of the product when a new plan is generated. From the perspective of the user, this translates to (Fig. 4) - "I don't like it that much", "I like it", and "I love it". For instance, a product rated with the first score will not stop being recommended to the user, but since it has a lower weight, it will be recommended less often.

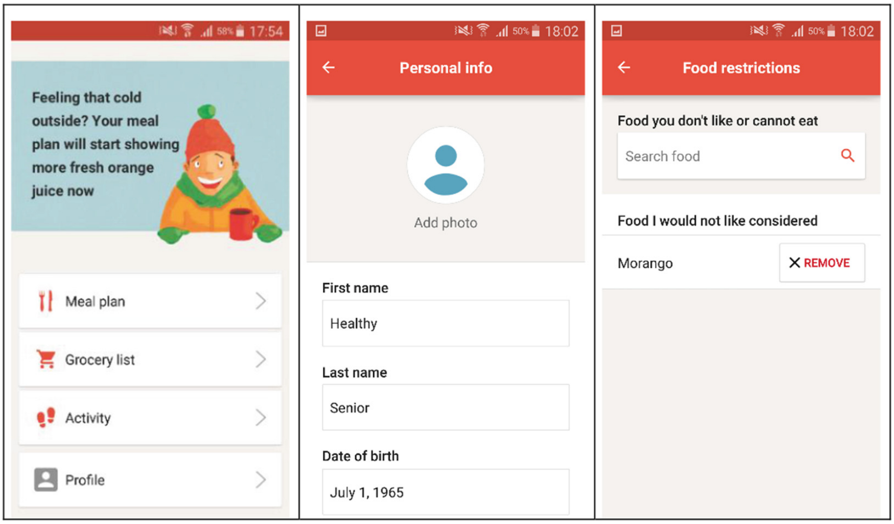

Fig. 2. SousChef main screen (left), personal information (center) and food restrictions (right) detail screens.

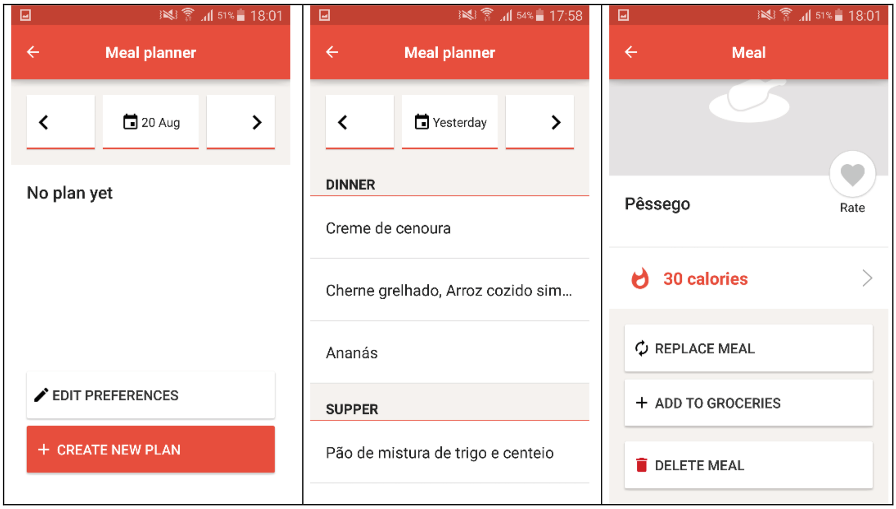

Fig. 3. Meal plan creation screens, when no plan was created and afterwards (left and center), and particular ingredient view (right).

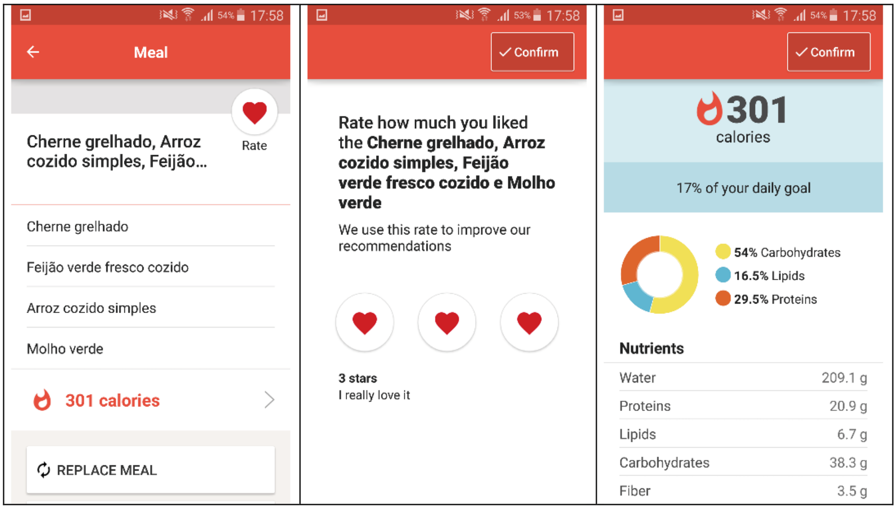

Fig. 4. Recipe ingredient view (left), rating screen (center) and nutrient information (right) details.

5.2 Grocery List

The goal of the Grocery List component is to help the user with shopping related activities. This component takes on a physical grocery list, but augments it with new capabilities (Fig. 5). Even though not being the central piece of SousChef, this component can be a valuable tool in the above mentioned goal to assist food management.

The main features of the Grocery List are the integration with the Meal Plan component and the ability to automatically add products to the list based on the ingredients of a recipe. In addition to these features, the user has also the option to manually add new products to the list based on a database search.

Since the goal of this component is to assist users in their shopping activities, there was the concern to design a user interface that would be easy to use in the wild, e.g. in the supermarket. Therefore, one characteristic of the system is the ability to work offline, so that the user does not need an Internet connection to access his or her grocery list while in the supermarket. Users are also able to mark products as bought as they go, and that information will be synchronized the next time there is an Internet connection. Moreover, products are organized by aisles to make the shopping process in the store more efficient.

5.3 Activity Monitoring

Along with nutrition, an important part of a healthy lifestyle is a person's activity level. The Activity Monitoring used in the SousChef presents the users with metrics related to their activity (Fig. 6).

Given that one of the inputs required by the system in order to generate new meals is the level of activity of the user, the Activity Monitoring component is responsible for

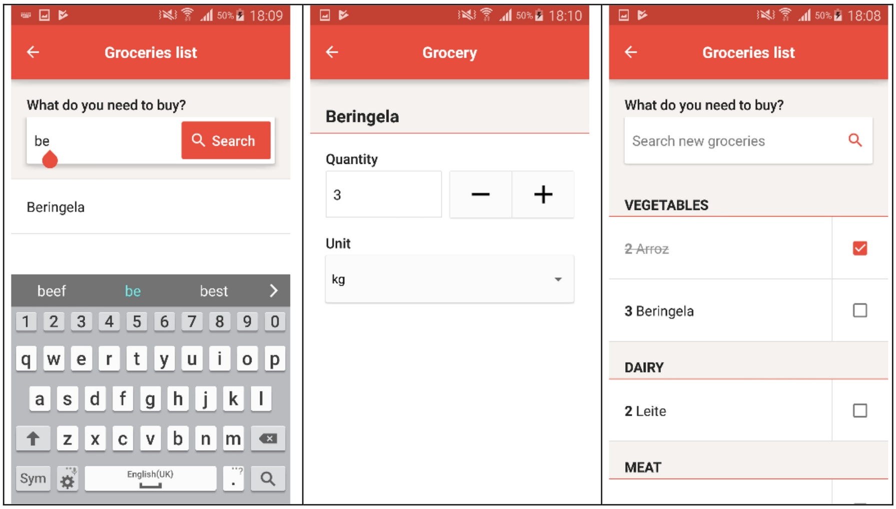

Fig. 5. Groceries list screens: search of products (left), product details (center) and groceries list overview (right).

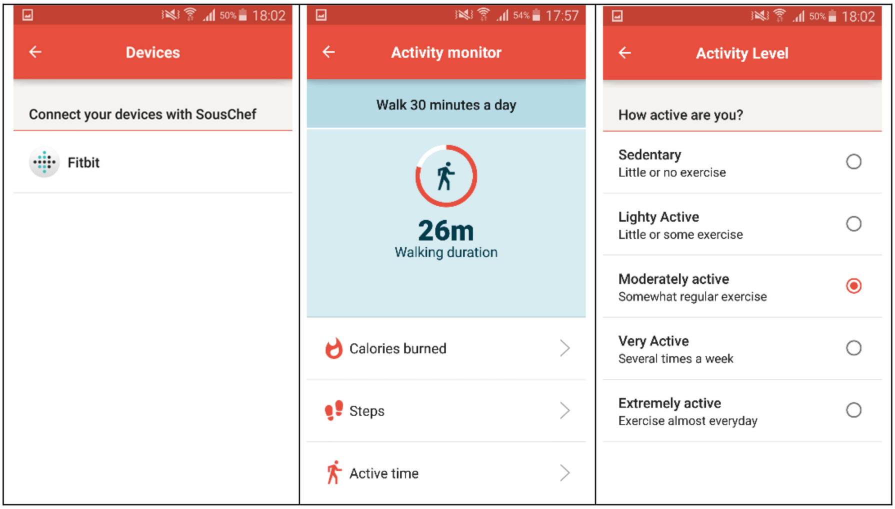

Fig. 6. Activity monitoring example screens: connection to Fitbit devices (left), available details on activity monitoring (center) and activity level scale (right).

collecting user activity data and feeding those data to the recommender engine. In order to do that the system can be connected to an activity monitoring device such as a Fitbit bracelet. Afterwards, the system is able to collect and display calories burned, steps and active time. For each of these metrics, daily objectives can be set in order to raise awareness to their healthy physical activity habits.

The information gathered from such devices is then converted to a scale that classifies the level of activity as belonging to one of five levels, ranging from "sedentary" to "extremely active". The advantage of using a wearable device such as Fitbit is that the user activity information can be collected seamlessly, without direct input, with a reasonable level of accuracy, and updated automatically to our system.

Nevertheless, and in order to free the system from dependence on external devices or systems, it is also possible to manually insert this information in the user profile. In such scenario, the charts with the user activity information would not be used.

6 Conclusions and Future Work

In this work important insights of potential stakeholders in the domain of nutrition of older adults are presented. This research focused on nutritionists, food management providers and older adults and aimed to gather the perspectives within this domain.

The presented results were of outmost importance for the design of SousChef, a mobile meal recommender system to assist older adults by providing a nutrition companion to guide them into making wise decisions regarding food management and healthy eating habits that has been firstly presented in [11].

Moreover, in this work an improved version of the meal recommender system is described based upon the results presented in [11]. Now the users can choose between 4 to 6 meals to be planned per day, in order to adapt to their preferences. Also new heuristics were added to the system to better reflect the Portuguese nutritional guidelines and information about food prices in order foster reducing waste and shortening one's shopping list. Finally, more details on the mobile application were here presented.

As future work, it is intended to realize an evaluation of the recommender output, namely to evaluate the adequacy of recommendations when different combinations are selected, from 4 to 6 meals per day. Another topic to be evaluated in the future is the adequacy of suggestion of alternative dishes for a meal. The current system allows users to get an alternative dish if they do not like the initial suggestion. This is a new feature and it was not tested before.

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Study on Indicators for Depression in the Elderly Using Voice and Attribute Information

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Abstract. As the age of the human population increases worldwide, depression in elderly patients has become a problem in medical care. In this study, we analyzed voice-emotion component data, attribute data, and Beck Depression Inventory (BDI) scores by multivariate analysis, particularly in the elderly, and proposed evaluation indicators for estimating the state of depression of elderly patients. We divided the data into two groups according to BDI scores: a state of depression and the absence of this state. The labels distinguishing the two groups were dependent variables, while the voice-emotion component and attribute information were set as independent variables, and we performed logistic regression analysis on the data. We obtained a prediction model with significantly sufficient fitness. In the receiver operating characteristic curve for the proposed depression evaluation indicator, a sorting performance with an area under the curve of approximately 0.93 was obtained.

Keywords: Voice · Emotion recognition · Depression
Beck depression inventory · Attribute information

1 Introduction

In recent years, society has become more aged worldwide [28]. Elderly people often develop depression because of physical impairment, anxiety about health, death of friends, and loneliness because of living alone, among other reasons; along with dementia, depression is common among elderly people [6].

Self-descriptive psychological tests such as General Health Questionnaire [11] and Beck Depression Inventory (BDI) [4] are commonly used as screening methods for mentally impaired patients. The self-descriptive psychological test is non-invasive and relatively simple, but it cannot eliminate the influence of reporting

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bias. Reporting bias is the selective underexposure or overestimation of specific information because of the consciousness/unconsciousness of the respondents [8].

In a previous study, we developed a method for estimating mental health state, such as depression state and stress state, based on voice information [14,24,27]. Analysis using voice is advantageous because it is noninvasive and does not require a special dedicated device, and can be performed easily and remotely. The authors focused on speech over telephone calls, which uses voice on a daily basis; using smartphones, which have become increasingly popular in recent years, we developed a system for monitoring mental health state from the voice at the time of a call (MIMOSYS: Mind Monitoring System) [20]. We hope that by using this system to monitor mental health state on a daily basis, it will become possible to prevent mental problems. MIMOSYS is based on Sensibility Technology (ST) [22], and digitizes and outputs the mental health state from voice. ST estimates the emotion of the speaker based on changing patterns in the fundamental frequency during a conversation. Five emotions, "calmness", "anger", "joy", "sorrow", and "excitement", are analyzed in the voice. In MIMOSYS, "vitality", which digitizes the health condition immediately after a call from the emotion analyzed by ST, and "mental activity", which quantifies medium- and long-term health condition, are outputted. By monitoring changes over time in the mental activity, it is possible to determine the health condition and may lead to self-medication, self-control, or early visit to a hospital. However, when trying to use MIMOSYS for screening, previous studies suggested that the mental activity correlates with the BDI score [12,13], while in our studies, this correlation was not clearly observed (unpublished). Thus, it is necessary to improve the accuracy of this technology.

In this study, we propose a voice evaluation indicator that differs from the mental activity for screening of depression state with better accuracy in the elderly. Additionally, this research expands upon the paper [14] presented at the Information and Communication Technologies for Aging Well and e-Health (ICT4AWE 2017), an international conference held in Porto, Portugal.

2 Method

2.1 Target

Subjects. Of the MIMOSYS users, we targeted those who were aged ≥ 65 years because the United Nation's World Health Organization defines elderly people as those aged ≥ 65 years.

MIMOSYS is open to the public as a smartphone application. In this system, after the user agrees to participate in research, an individual ID is assigned to the user and registered in a dedicated server in an anonymized state. Attribute data by a questionnaire such as age at the time of registration is also saved. Every time a user makes a phone call using a smartphone, the analysis result is recorded on the same server. Analysis results include emotional components/mental activities. Voice at the time of calling is temporarily recorded on the smartphone, analyzed on the smartphone when the call ends, recorded as an analysis result in the server, and immediately deleted.

In this study, we analyzed data collected from July 20, 2015, which is the first date of MIMOSYS availability, to July 20, 2016. During this time, the total number of downloads was almost 3000; of these, 1456 users agreed to participate in the research, responded to the questionnaire at the time of enrollment, and spoke on the phone. However, after users for whom data could not be properly collected depending on the situation of the communication were excluded, 1436 subjects remained. Of these, 35 people were $\geq$ 65 years of age. Table 1 shows the details for all users who made calls.

Table 1. Details of all users who made calls (from [14]).

		Male	Female	Total
Age	16–19	22	27	49
	20–29	155	147	302
	30–39	235	142	377
	40–49	242	141	383
	50–59	165	74	239
	60–64	39	12	51
	65–69	20	8	28
	70–74	2	2	4
	75–79	2	1	3
Total		882	554	1436

The mean age across the entire population was 40 years (SD = 12), with averages of 41 years (SD = 12) for males and 37 years (SD = 12) for females. The minimum age was 16 years for both males and females, while the maximum age was 76 years for males and 75 years for females.

BDI Score. In MYMOSYS, a BDI questionnaire is performed on a smartphone every 3 months from the start of system use, and its score is recorded on the same server. Of the 35 subjects, we analyzed 33 users aged above 65 years who made phone calls within 2 weeks of the BDI questionnaire. Data collected within 2 weeks of the BDI questionnaire were judged to be effective because the diagnostic criteria of DSM-IV [3] for depression suggests that a state should be maintained for at least 2 weeks. In addition, for users who completed the BDI questionnaire multiple times, we analyzed data collected within 2 weeks of each questionnaire. Finally, we obtained efficacy data for 41 BDI scores from 33 subjects.

We also grouped data from analysis targets based on the criteria for evaluating the BDI score. Although there have been multiple studies of the criteria for evaluating BDI score [7, 17], because highly accurate patient screening results have been reported for the criteria used by Beck et al. [5], we used the same criteria in the present study. This criteria for evaluation are shown in Table 2.

Table 2. Evaluation criteria of BDI score.

BDI score	0–10	Ups and downs are considered normal
	11–16	Mild mood disturbance
	17–20	Borderline clinical depression
	21–30	Moderate depression
	31–40	Severe depression
	41–63	Extreme depression

In this study, we conducted verification by dividing the subjects into two groups, one with BDI scores of ≥ 17 that require a physician's diagnosis (clinical depression) and those with BDI score < 17 and not requiring a diagnosis (normal). This threshold value of a BDI score of 17 is a boundary value for the state of depression. The number of people belonging to the former group and latter group was 3 and 30, respectively. In addition, for users who conducted the BDI questionnaire multiple times, those classified to the clinical depression group based on the first BDI score also had a BDI score of ≥ 17 from the second and subsequent times. Users classified into the normal group based on the first BDI score also had BDI scores of < 17 from second and subsequent times. Therefore, there were no overlapping users between the two groups.

Voice Data. A total of 672 pieces of effective voice data were collected within 2 weeks of the BDI questionnaire for the 33 subjects. In the clinical depression and normal groups, the numbers of voice data obtained were 50 and 622, respectively.

2.2 Analysis of Emotion

MIMOSYS estimates mental health based on components of emotions contained in the voice. There are 5 types of emotions analyzed by MIMOSYS, calmness, anger, joy, sorrow, and excitement, calculated with ST, and each component is calculated with real numbers $[0, 1]$. A value of 0 indicates that the input voice contains none of the emotions in question. A value of 1 indicates that the emotion in question is certainly contained in the input voice.

The minimum unit of voice-emotion analysis by MIMOSYS is "utterance", which indicates continuous speech punctuated by respiration. In practice, the start of speech is detected when the state of silence changes to state of utterance, and this condition is maintained for a certain period. A state of utterance or state of silence is identified by thresholding the amplitude value of the temporal waveform of the voice.

2.3 Logistic Regression Analysis

For logistic regression analysis [2], the clinical depression group and normal group were represented by qualitative values of 1 and 0, respectively. These numbers were used as labels to distinguish the two groups and were assigned to dependent variables during logistic regression analysis.

In logistic regression analysis, a logistic curve rather than a line was fitted to the model. Thus, if the dependent variable is Y and the independent variables are $X_1,\ X_2, \ldots,\ X_n$, the following predictive formula is obtained from [14]:

$$Y = \frac{1}{1 + \exp\left(-\alpha_0 - \alpha_1 X_1 - \alpha_2 X_2 - \cdots - \alpha_n X_n\right)} \tag{1}$$

In this study, analysis was carried out by making depression state level a dependent variable and making emotional components and attribute information independent variables as follows:

$$\begin{aligned} Y &= (\text{Depression state}), \\ X_1 &= (\text{Calmness}),\ X_2 = (\text{Anger}), \\ X_3 &= (\text{Joy}),\ X_4 = (\text{Sorrow}),\ X_5 = (\text{Excitement}) \\ X_6 &= (\text{sex}),\ X_7 = (\text{Age}),\ X_8 = (\text{History of current illness}) \end{aligned} \tag{2}$$

where the depression state is a qualitative value resulting from thresholding the BDI score, and calmness, anger, joy, sorrow, and excitement are emotional values analyzed by MIMOSYS (from [14]). Sex is a qualitative variable and is treated as a dummy variable in analysis. The history of current illness is the number of diseases affecting a subject when responding to the questionnaire. In the analysis, the emotional value for each call, BDI score within the immediate last two weeks, and attribute information at the time of responding to the questionnaire were set as one data set.

The performance of the prediction formula obtained by analysis was evaluated by the sensitivity, specificity, and area under the curve (AUC) of the receiver operating characteristic (RUC) curve with a cutoff point of 17 of the BDI score.

For statistical processing, the Free Software R version 3.3.2 was used for statistical analysis.

3 Results

3.1 BDI Score and Number of Calls

The minimum, maximum, and mean BDI scores were 0, 28, and 8.53 (SD = 6.50), respectively.

The mean number of calls per person during the 2 weeks after the BDI questionnaire was 16.78 times (SD = 25.66).

Each histogram is shown in Fig. 1 and Fig. 2. There were 30 people with BDI scores less than 17, and although each score was distributed uniformly, because

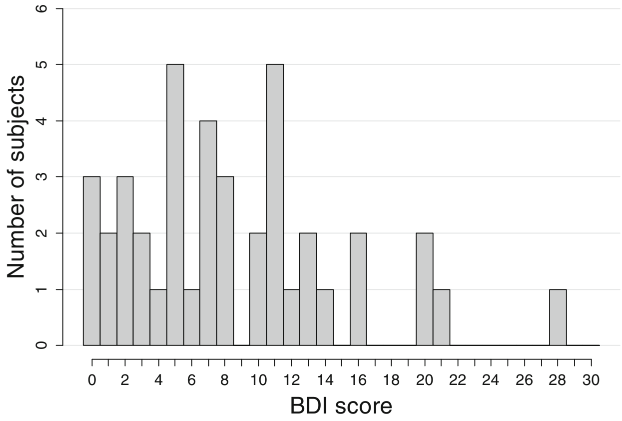

Fig. 1. Distribution of BDI scores for system users (modified from [14]).

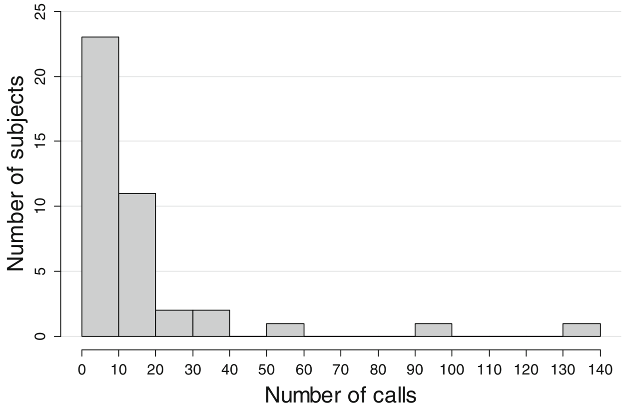

Fig. 2. Distribution of the number of calls for system users (modified from [14]).

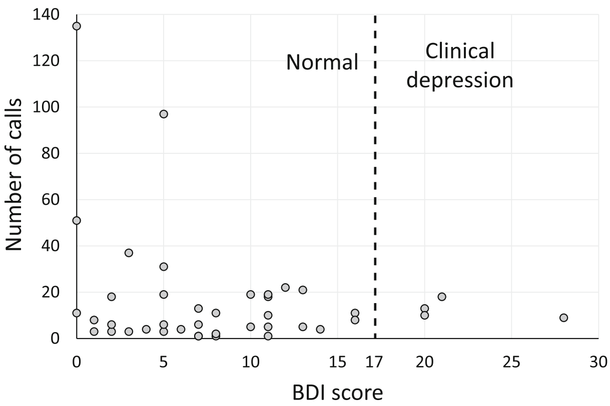

Fig. 3. Scatter plot of BDI scores and number of calls (modified from [14]).

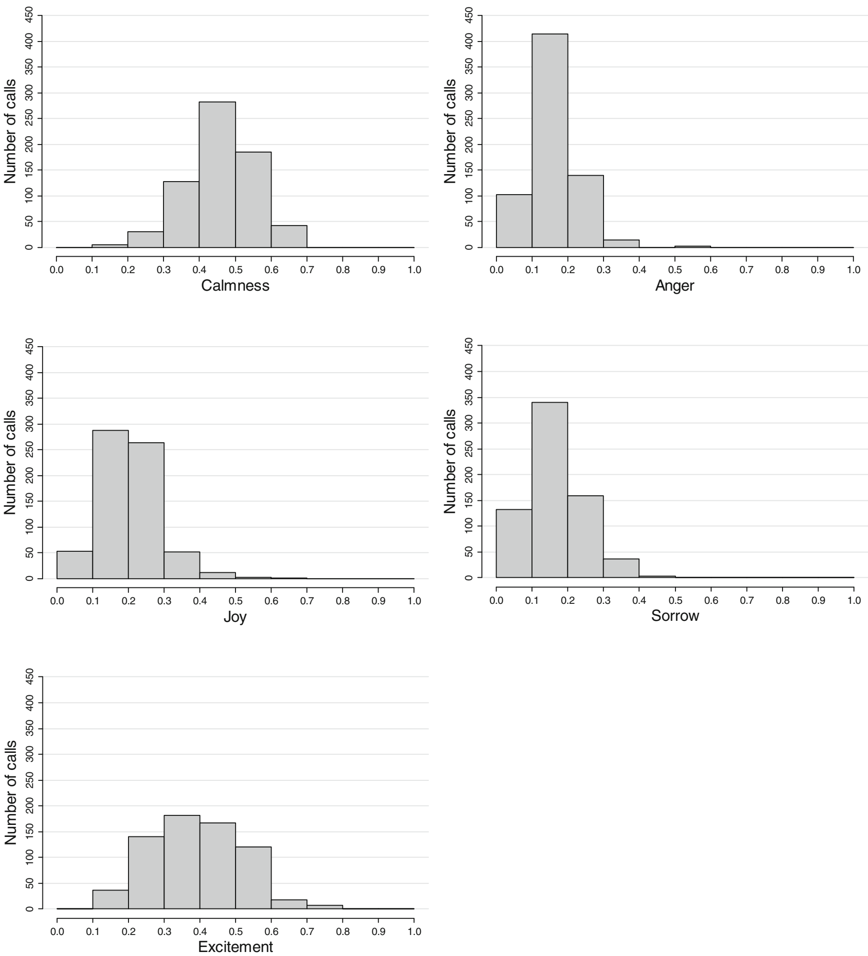

Fig. 4. Distribution of each emotional component for system users (modified from [14]).

there were only 3 people with scores of 17 or more, these people were sparsely distributed (Fig. 1). The number of calls was $0 \sim 20$ (Fig. 2).

A scatter plot of the BDI score and number of calls per person during the 2 weeks after the BDI questionnaire is shown in Fig. 3. Spearman's rank correlation coefficient [25] was calculated as a correlation coefficient independently of the BDI score and type of distribution of the number of calls. As a result, the coefficient was -0.015 ($p = 0.92 > 0.01$), indicating no significant correlation.

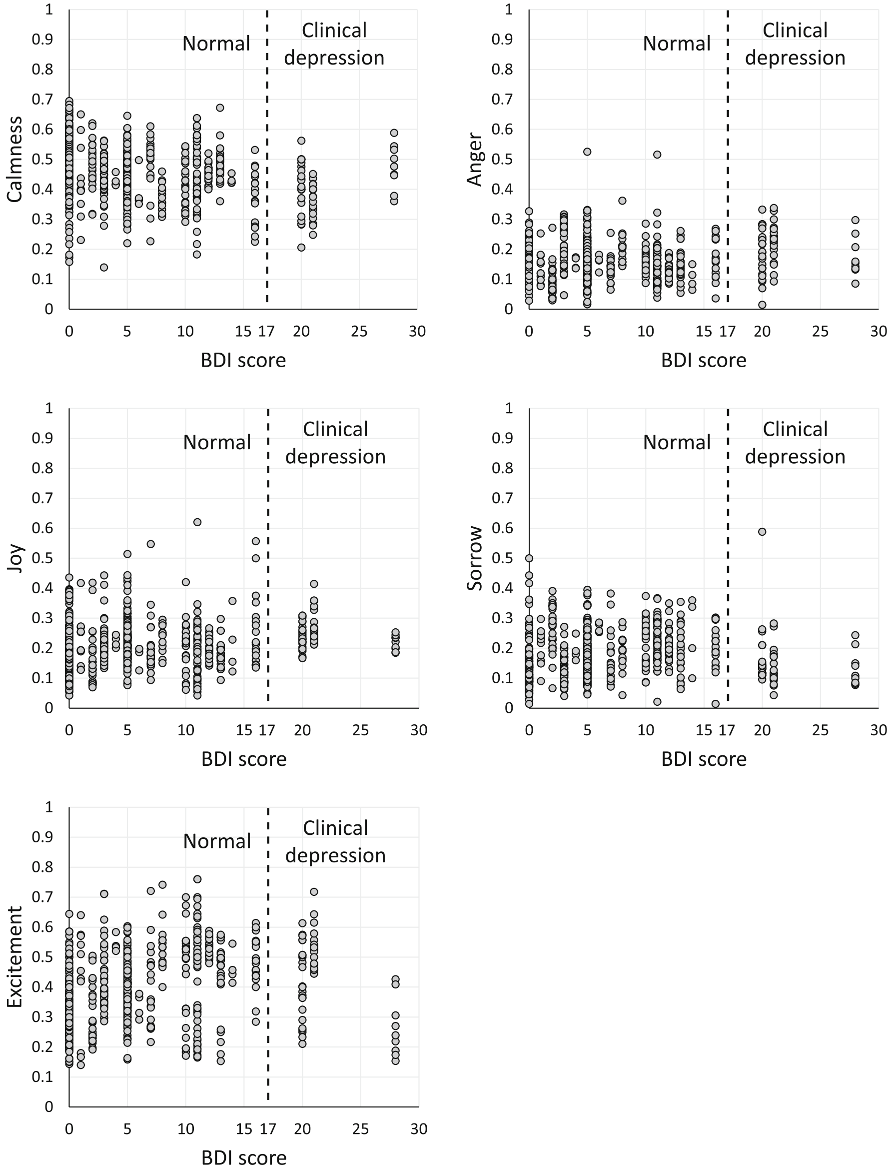

Fig. 5. Scatter plots of BDI scores and each emotional component (modified from [14]).

3.2 Distribution of Emotional Components

Figure 4 shows a histogram of each emotional component. Calmness and excitement were most commonly present in the voices used in analysis, with low values for anger, joy, and sorrow.

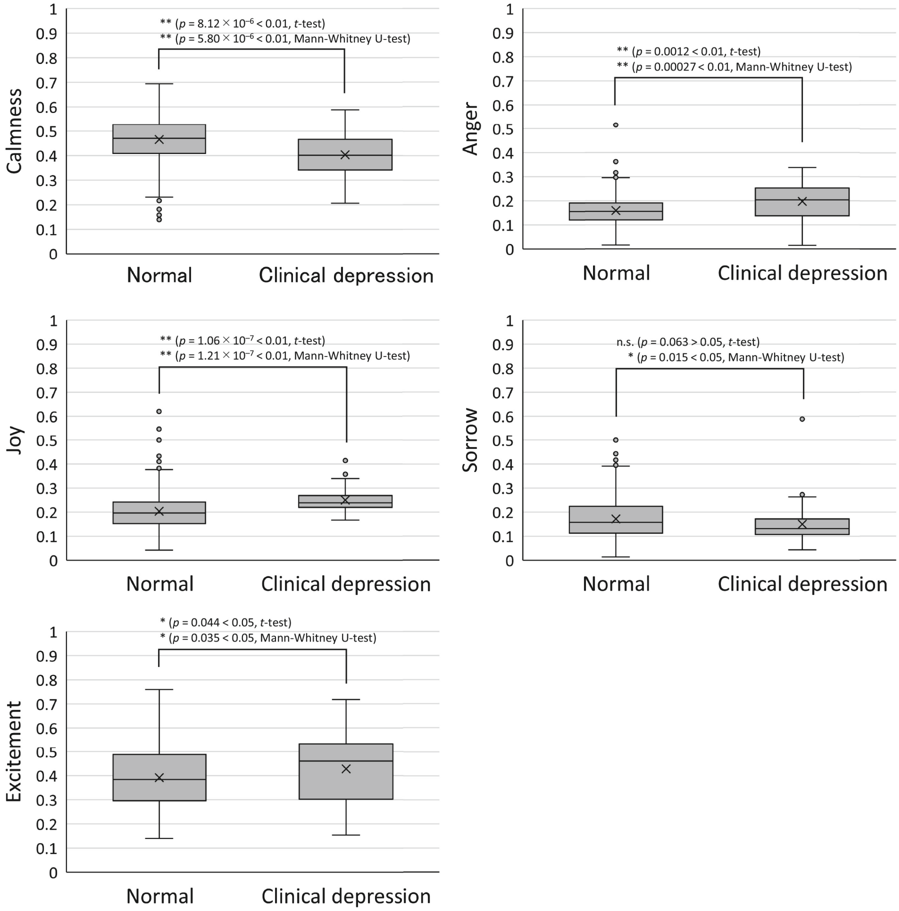

Fig. 6. Distributions of normal and clinical depression for each emotional component.

A scatter plot of BDI scores and each emotional component is shown in Fig. 5. Spearman's rank correlation coefficients between the BDI score and each emotional component (calmness, anger, joy, sorrow, excitement) were -0.36 ($p < 2.20 \times 10^{-16} < 0.01$), -0.077 ($p = 0.046 < 0.05$), 0.19 ($p = 4.72 \times 10^{-7} < 0.01$), 0.30 ($p = 2.23 \times 10^{-15} < 0.01$), 0.39 ($p < 2.20 \times 10^{-16} < 0.01$), respectively. Despite the significant correlation between all emotional components and BDI scores, anger and joy showed nearly no correlation with the BDI scores based on the evaluation criteria of the correlation coefficient.

Figure 6 shows the distribution of each emotional component for the normal and clinical depression groups in a box-and-whisker plot. A t-test to evaluate differences in the normal and clinical depression groups with respect to each emotional component revealed significant differences for all emotional components except sorrow. The Mann-Whitney U-test [21], which does not depend on

Table 3. Contingency table of depression state and sex.

	Male	Female
Normal	22 (418)	15 (204)
Clinical depression	2 (19)	2 (31)

$p = 7.79 \times 10^{-5} < 0.01$

the type of distribution of the two groups, revealed significant differences in all emotional components.

3.3 Distribution of Attribute Information

Sex. Table 3 is a contingency table of the depression state and sex. In the table, the numbers in brackets represent the number of data points. A relationship between depression state and sex was observed by Fisher's exact test [9].

Age. A scatter plot of BDI scores and age is shown in Fig. 7. The Spearman's rank correlation coefficient between BDI scores and age was 0.18 ($p = 0.25 > 0.01$), indicating no significant correlation.

When statistically evaluating the differences between the normal and clinical depression groups, neither the t-test ($p = 0.40 > 0.01$) nor Mann-Whitney's U-test ($p = 0.89 > 0.01$) revealed significant differences between groups.

History of Current Illness. A scatter plot of BDI scores and number of current illnesses is shown in Fig. 8. The Spearman's rank correlation coefficient

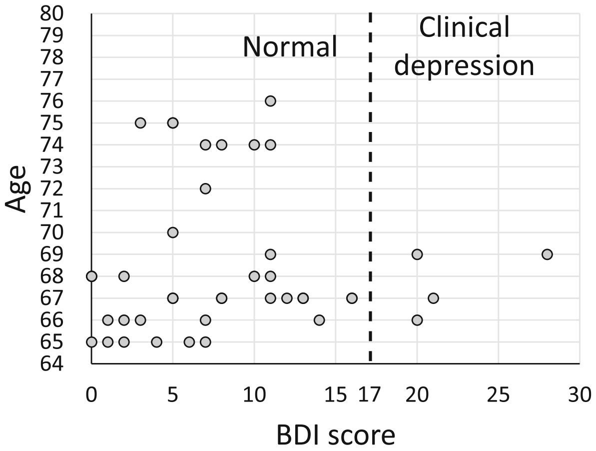

Fig. 7. Scatter plot of BDI scores and age.

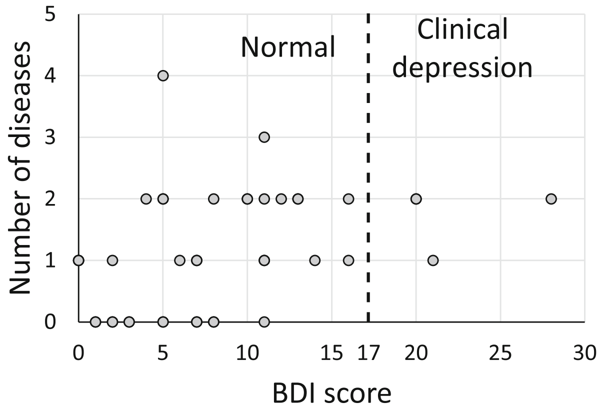

Fig. 8. Scatter plot of BDI scores and current illnesses.

between BDI score and the number of current illnesses was 0.45 ($p = 0.0032 < 0.01$), indicating a significant, moderately positive correlation.

Evaluation of the difference between the normal and clinical depression groups revealed no significant differences between groups according to the t-test ($p = 0.066 > 0.01$) and Mann-Whitney's U-test ($p = 0.13 > 0.01$).

3.4 Regression Coefficient

The results of the logistic regression analysis using the variable increase and decrease method together are shown in Table 4.

The estimates in the table represent the coefficients for the independent variables in the prediction formula (1). The variables chosen using the variable increase and decrease method were of 7 types, X_2 to X_8, while X_1 (calmness)

Table 4. Results of logistic regression analysis.

	Estimate	Std. Error	z value	$Pr(>\|z\|)$	
Intercept	19.20	5.58	3.44	0.00059	**
X_2 (Anger)	19.97	4.00	4.99	6.01×10^{-7}	**
X_3 (Joy)	19.10	3.34	5.72	1.06×10^{-8}	**
X_4 (Sorrow)	9.61	3.69	2.61	0.0091	**
X_5 (Excitement)	−17.30	2.99	−5.78	7.39×10^{-9}	**
X_6 (Sex)	−3.40	0.58	−5.90	3.75×10^{-9}	**
X_7 (Age)	−0.35	0.077	−4.51	6.53×10^{-6}	**
X_8 (Current illness)	1.21	0.25	4.88	1.05×10^{-6}	**

was removed because it did not contribute to Y (depression state). Accordingly, the coefficient of X_1 was 0, and the prediction formula was as follows:

$$\begin{aligned} Y &= \frac{1}{1+\exp\left(-19.20-E-A\right)}, \text{ where} \\ E &= 19.97X_2 + 19.10X_3 + 9.61X_4 - 17.30X_5 \\ A &= -3.40X_6 - 0.35X_7 + 1.21X_8 \end{aligned} \tag{3}$$

When the fitness of the predicted model was evaluated using the Phosmer-Lemeshau test [2], a p-value of 0.76 was obtained. In this test, a greater significance probability indicates better fitting of the model. Therefore, sufficient fitness was demonstrated for the predicted model.

3.5 Distribution of Predicted Values

Using prediction formula (3), it is possible to predict the probability of a subject being in the clinical depression group based on each emotional component contained in the voice and attribute information. This predicted value is defined as the "Depression Evaluation Indicator (DEI)" for elderly people. A scatter plot of BDI score and DEI is shown in Fig. 9. Spearman's rank correlation coefficient between BDI score and DEI was 0.26 ($p = 1.31 \times 10^{-11} < 0.01$), indicating a significant and weakly positive correlation.

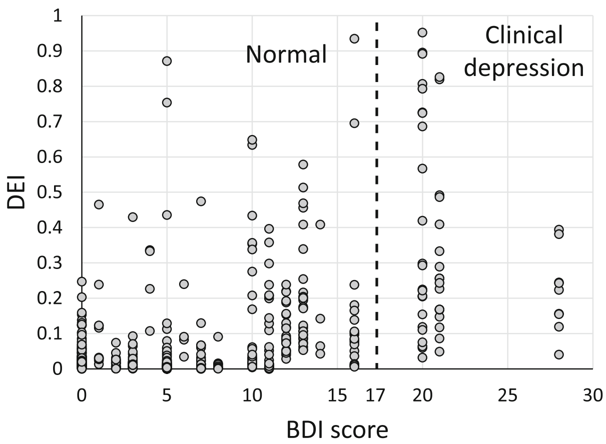

Fig. 9. Scatter plot of BDI score and DEI.

Figure 10 shows the distribution of DEI in each group as a box-and-whisker plot. When the difference in DEI between the two groups was evaluated, both the t-test and Mann-Whitney's U-test confirmed a significant difference.

The mean DEI values for males and females were 0.13 and 0.043, respectively. The distributions of male and female groups were significantly different according

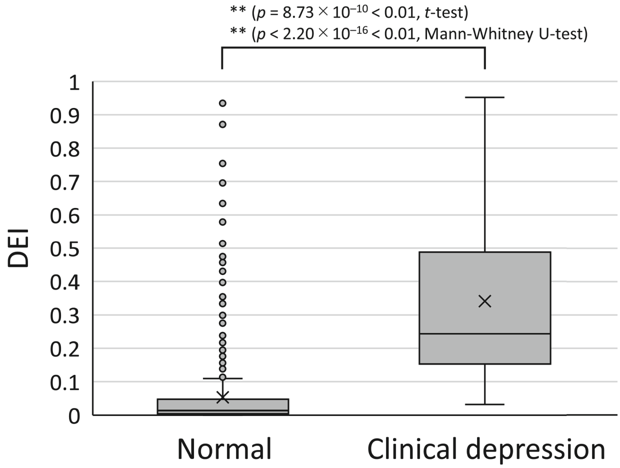

Fig. 10. Distribution of normal and clinical depression with respect to DEI.

to both the t-test and Mann-Whitney's U-test ($p = 8.92 \times 10^{-10}$ and $p = 8.38 \times 10^{-11}$, respectively).

Furthermore, for 0, 1, 2, 3, and 4 current illnesses, the mean DEI values were 0.029, 0.049, 0.13, 0.044, and 0.69, respectively. Multivariate analysis with the Steel-Dwass method [26] revealed significant differences in groups with 0–1, 0–2, 0–4, 1–4, and 2–4 current illnesses.

3.6 ROC Curve

The ROC curve (solid line) for DEI is shown in Fig. 11. For comparative evaluation, the ROC curve (dotted line) for the prediction formula (DEI-emotion-Only) [14] when analyzing only the emotional component as the independent variable and ROC curve (dashed line) against the vitality of MIMOSYS are also shown. A higher vitality of MIMOSYS indicates a better mental state. For the data used in this analysis, the vitality of data belonging to the normal group showed low values, and the vitality for data belonging to the clinical depression group was distributed at high values, resulting in an interpretation that contradicts the original interpretation of vitality. Therefore, the ROC curve of the vitality was calculated by reversing the interpretation of vitality.

For DEI-emotion-Only, the AUC under the ROC curve was 0.76, whereas the AUC for DEI was 0.93.

For DEI, the point at which the perpendicular from the ROC curve to AUC = 0.5 was the longest was the point at which sensitivity and specificity were 0.86 and 0.87, respectively, and the threshold of DEI at that time was 0.11. The confusion matrix for this threshold is shown in Table 5.

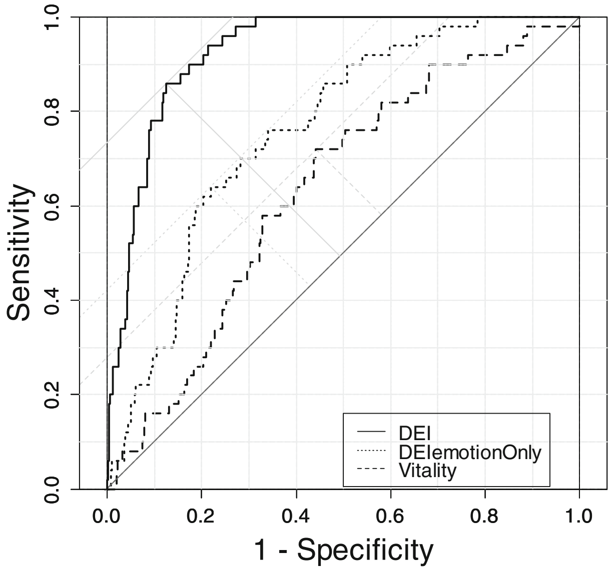

Fig. 11. ROC curve for DEI, DEI-emotion-Only, and Vitality.

Table 5. Confusion matrix for DEI.

		BDI	
		Normal (BDI $<$ 17)	Clinical depression (BDI $\geq$ 17)
DEI	Low($<$ 0.11)	544	7
	High($\geq$ 0.11)	78	43

3.7 Classification of Three Groups

To further evaluate the performance of the prediction model, we investigated the classification ability of three groups. Based on the BDI score evaluation criteria (Table 2), the normal group was further divided into two groups: healthy and borderline. The borderline group showed BDI scores between 11 and 16, which is a light depression state and does not require a physician's diagnosis but cannot be regarded healthy. For these three groups, a box-whisker plot of the DEI distribution is shown in Fig. 12. When multiple comparisons were carried out using the Steel-Dwass method, significant differences were observed among all groups.

The ROC curve for healthy and borderline is shown in Fig. 13 and the ROC curve for borderline and clinical depression is shown in Fig. 14. The values of the area under the curve (AUC) for the ROC curves were 0.70 and 0.82, respectively.

In Figs. 13 and 14, the points with the highest sensitivity and specificity are $(1 - 0.80,\ 0.64)$ and $(1 - 0.66,\ 0.86)$, respectively, and the threshold values of

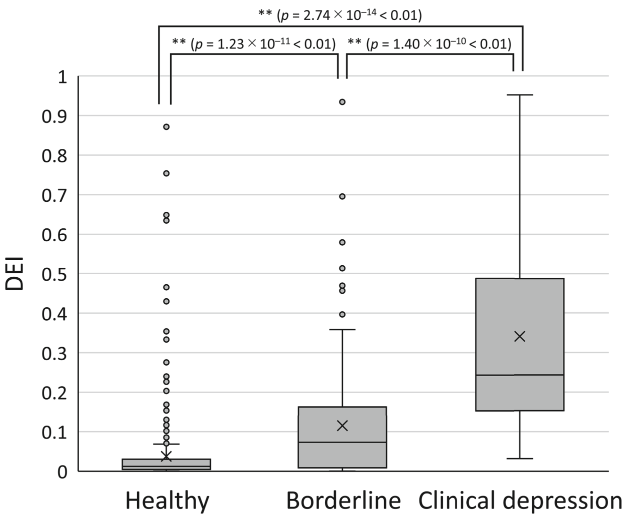

Fig. 12. DEI distribution for healthy, borderline, and clinical depression.

DEI at that time were 0.036 and 0.11, respectively. The confusion matrices for these thresholds are shown in Tables 6 and 7, respectively.

4 Discussion

One limitation of this study is that little validation data is available. The usage rate of smartphones among the elderly is low and some users downloaded but did not use the application. It may be necessary to collect data from the elderly using another method.

Because the probability of the independent variable coefficient was significant for all selected variables, the probability appeared to be related to the depression state of the elderly. Although the anger and joy components showed nearly no correlation with BDI score, they may greatly impact the depression state based on the sign and magnitude of the independent variable coefficients. The depression state involves the symptom "getting angry and irritated", and the result for which the emotional component of anger has a great influence coincided with this symptom. The result greatly influenced by the emotional component of joy did not match the symptoms of a depression state. Based on the main symptoms of the depression state, the component of sorrow showed the strongest relationship with the degree of depression, which differed from our hypothesis. This may be because the sorrow component was weakly correlated with the BDI score, but the clinical depression distribution was somewhat lower than the normal. Additionally, in this analysis, there was no data for elderly people with a BDI score of ≥ 30. Because the group requiring a physician's diagnosis was only in a state of moderate depression, it is possible that the influence of the sorrow

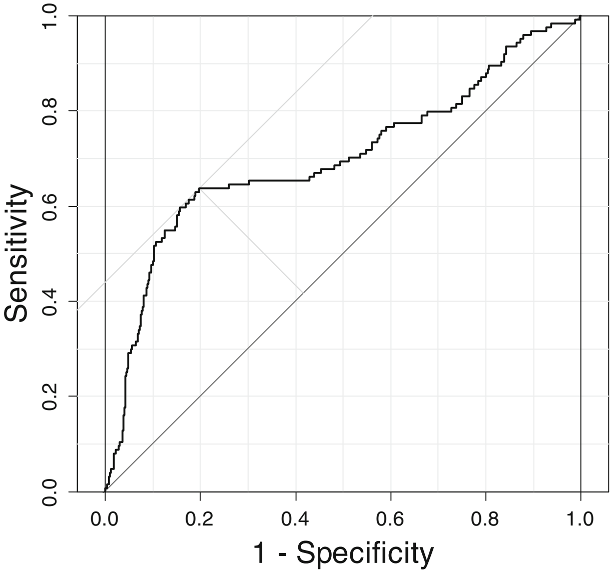

Fig. 13. ROC curve for healthy and borderline.

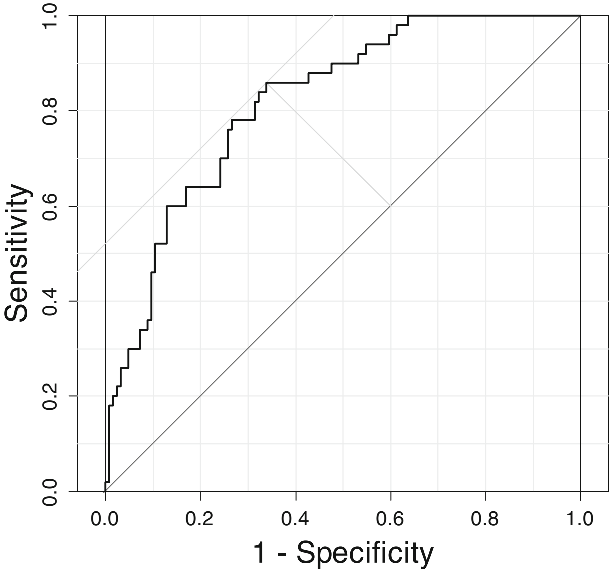

Fig. 14. ROC curve for borderline and clinical depression.

component was underestimated. The excitement component had a large and negative influence on depression state, which is consistent with "loss of motivation", one of the symptoms of depression. Regarding the calmness component, a weak

Table 6. Confusion matrices for healthy and borderline.

		BDI	
		Healthy (BDI $<$ 11)	Borderline (11 $\leq$ BDI $<$ 17)
DEI	Low($<$ 0.036)	400	45
	High($\geq$ 0.036)	98	79

Table 7. Confusion matrices for borderline and clinical depression

		BDI	
		Borderline (11 $\leq$ BDI $<$ 17)	Clinical depression (BDI $\geq$ 17)
DEI	Low($<$ 0.11)	82	7
	High($\geq$ 0.11)	42	43

correlation was observed with the BDI score; thus, this component was not involved in the depression state, despite the significant difference observed between the clinical depression and normal groups. Because the four emotions of "calmness", "anger", "joy", and "sorrow" were outputted to 100 percent, if the feelings of "joy" and "sorrow" are suppressed and "anger" does not change, "calmness" correspondingly increases, which may have affected the judgment. The change in emotion estimated from the above symptoms and results of this study require further analyses. Sex showed a link with BDI score, which was reflected in the model. Based on the sign of the independent variable coefficient, women tended to have a higher DEI than men. This is consistent with the fact that women tend to be more depressed than men [18]. Age was not correlated with the BDI score, and the model revealed no significant difference between clinical depression and normal subjects. In fact, the independent variable coefficient value showed a lower value than the other values, indicating that it did not have a large effect on depression state. Because the number of current illnesses was moderately and positively correlated with BDI, it was considered as related to depression. According to the sign of the independent variable, DEI generally increased as the number of diseases increased, and the number of current illnesses was successfully reflected in the model. This is consistent with the fact that a patient is more likely to become depressed if he/she is afflicted with multiple diseases [19], but among the data used for analysis, 3 and 4 current illnesses was observed only in the normal group. Half of the data were erroneously discriminated as clinical depression, and the influence of the number of current illnesses on the model was not accurately reflected.

The prediction formula obtained by analysis fit well with the data based on the fitness test. In addition, because there was a significant difference in the distribution of DEI for the clinical depression and normal groups, this indicator can be used to screen elderly people with depression. The performance of the evaluation indicator as a classifier according to sensitivity, specificity, and AUC showed a high value, and the performance was improved remarkably compared to the model that only included emotional components. However, it is necessary to apply the prediction formula obtained in this study to other data to verify its accuracy.

Although the model was used for two groups of classifiers, the proposed evaluation indicator showed good performance for classifying 3 groups but should be improved. The normal group was divided into healthy and borderline groups; by adding the clinical depression group, we established 3 groups. The borderline group was in a state of mild depression. This demonstrates that this indicator is also effective for classifying the severity of depression.

In the depression state, there is a characteristic decrease in the expression of emotion, so we developed MIMOSYS to detect trends in the emotional components of voice. In this study, we investigated the association between emotional components, attribute information, and a depressed state. In the future, we will consider using not only voice, but also activity data using a smartphone's acceleration sensor and examining their relationships with depression state. Existing approaches for detecting depression state use biometric information obtained from various sensors other than voice, such as heart rate [10], electroencephalogram [1], and facial expression [16]. Invasive approaches include the use of saliva [15] and blood [23], and this information should be incorporated into models developed in future studies.

The number of voice features reflecting emotional components may also be involved in depression. We will also consider selecting new voice features that reflect a depression state and further improve the accuracy of our model.

5 Conclusion

In this study, we used multivariate analysis to analyze voice emotional component data, attribute data, and BDI score collected from users of a system that monitors the mental health state based on the voice quality of individuals during calls on a smartphone and proposed an evaluation indicator for estimating the depression state in elderly people. Dividing data from elderly people into a group requiring a physician's diagnosis and group that does not require diagnosis based on the BDI score and performing logistic regression analysis resulted in a statistically adequate fitness prediction model. In the ROC curve for the proposed depression evaluation indicator, sorting performance by AUC was approximately 0.93. Furthermore, we divided the collected data into healthy, borderline (mild depression state), and clinical depression (requiring physician's diagnosis) groups and evaluated the sorting performance using the proposed evaluation indicator, which showed moderate performance. This suggests that the proposed depression evaluation indicator is also effective for classifying the severity of depression.

These results suggested that the proposed evaluation indicator is effective for screening depression patients among elderly people.

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Laying the Foundation for Correlating Daytime Behaviour with Sleep Architecture Using Wearable Sensors

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Abstract. The paper presents results from the SmartSleep project which aims at developing a smartphone app that gives users individual advice on how to change their behaviour to improve their sleep. The advice is generated by identifying correlations between behaviour during the day and sleep architecture. To this end, the project addressed two sub-tasks: detecting a user's daytime behaviour and recognising sleep stages in an everyday setting. In the case of daytime activity detection the best results were achieved using an accelerometer at the wrist and another one at the ankle (87%). A subsequent smoothing step increased the accuracy to over 90%. For recognising sleep architecture we experimented with various consumer wearables that we used in addition to the usual PSG sensors in a sleep lab. Several sleep stage classifiers were learned from the resulting sensor data streams segmented into labelled sleep stages of 30 s each. Apart from handcrafted features we experimented with unsupervised feature learning based on the deep learning paradigm. Our best results for correctly classified sleep stages are between 86 and 90% for Wake, REM, N2 and N3, while the best recognition rate for N1 is 37%. Finally, we discuss a preliminary design of the algorithm for determining correlations between daytime behaviour and sleep architecture.

Keywords: Sensor data analysis · Sleep stage recognition
Activity recognition · Deep learning · Behavioural change support
Complex activities

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1 Introduction

Sleep disorders such as insomnia or sleep apnea are wide-spread and are on the increase, especially because of an ageing population. Changes in the patterns of our sleep – what specialists call "sleep architecture" – occur as we age and tend to contribute to sleep problems [1]. But apart from ageing, other factors have shown to contribute to sleep disorders, such as lack of ambient light, lack of physical activity or stress [2].

Sleep disorders often remain undiagnosed and untreated even though they are a significant cause of morbidity and mortality [3]; for a detailed review of sleep disorders see [4]. Overall, experts agree that the prevalence of sleep disorders such as obstructive sleep apnea (OSA) or daytime sleepiness tends to be underestimated.

Sleep disorders often coincide with chronic health problems such as diabetes, hypertension, obesity as well as cardiovascular and psychiatric diseases such as depression. According to a recent survey [5], about 20% of people in Switzerland suffer from sleep disorders. About 28% of those affected were taking sleeping pills on a regular basis. Approximately 80% of patients with depression also complained about sleep disorders which can be considered predictors of future depression. According to a meta analysis of over 20 published longitudinal studies between 1980 and 2010, insomnia doubles the risk of suffering from depression [6].

Traditionally, sleep disorders are investigated in sleep laboratories by means of polysomnography (PSG) as well as by actigraphic assessment. A polysomnogram or sleep study usually involves the measurement of brain activity through the electroencephalogram (EEG), muscular activity (EMG) and eye movements (EOG). Other parameters monitored include oxygen saturation, respiratory effort, cardiac activity as well as sound and movement activity.

But not only is such sleep monitoring costly, it also removes people from their normal sleeping environment and prevents repeated or longitudinal studies. Recently, smart watches, fitness trackers as well as sensors built into a smartphone offer new opportunities for continuous monitoring in everyday settings. Sensors and wearables can capture data about people's rest and activity patterns. Most devices use accelerometers for tracking movements during the night from which they derive information on sleep architecture and sleep quality. Some devices take additional vital parameters into account, such as heart rate and skin conductance.

However, the tracking devices and sleep screening apps currently available cannot compete with the accuracy of clinical sleep laboratories. At best, they are able to distinguish between waking time and sleep time. When we compared different devices that claim to distinguish sleep stages we found little match between the identified sleep stages. Besides, according to a review of current sleep screening applications conducted by Behar and his team [7] none of the existing sleep monitoring applications available for smartphones with the exception of simple questionnaires, is based on scientific evidence.

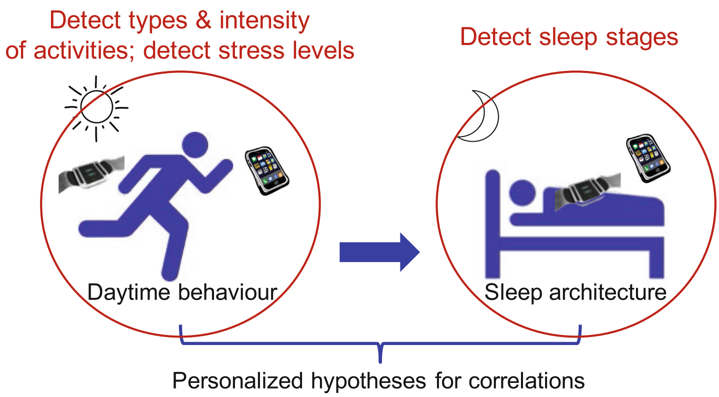

Fig. 1. The objectives of the SmartSleep project (from [8]).

Given the shortcomings of existing solutions for monitoring sleep architecture in a home setting, the SmartSleep[1] Project set out to achieve the following *objectives* (cf. Fig. 1):

– Develop a low-cost monitoring solution for capturing sleep architecture at home over a longer period of time with an accuracy approximating a clinical polysomnography (see right part of Fig. 1),
– collect data about a user's daytime behaviour, stress levels, and environmental factors (see left part of Fig. 1),
– identify correlations between a person's daytime behaviour and sleep architecture and track the person's response to simple behavioural changes, e.g. taking a walk in the evening or more exposure to ambient light during the day (the arrow in the middle of Fig. 1).

The *ultimate goal* of the project is to automatically generate individual advice for behavioural changes based on the insights gained from the tracking during the day and the night. This should open up new opportunities both for developing lifestyle and medical applications, for example:

– Depression: monitor the individual cognitive-behavioural insomnia therapy with a particular focus on sleep restriction and stimulus control;
– Gerontology: monitor sleep and waking rhythms for the diagnosis and validation of therapeutic measures for stabilising sleep/wake phases;
– Rehabilitation: monitor and quantify the impact of activity and movement as well as of sleep quality on the rehabilitation process.

[1] The SmartSleep project is funded by the International Bodensee Hochschule. The consortium includes the Universities of Applied Sciences of St. Gallen, of Vorarlberg and of Constance, the Center for Sleep Research and Sleep Medicine at the Swiss Clinic Barmelweid and the two SMEs Biovotion and myVitali.

The correlations between daytime behaviour and sleep architecture discovered by data mining are highly *personal* because individuals differ greatly with regard to what may promote and what may hinder sleep. Whereas for one person a walk in the evening is very conducive to a good night's sleep, someone else may get too agitated. This is why in the project we focus on recognising patterns that apply to a specific individual rather than on statistical correlations in a population.

To achieve the project goals we have proceeded as follows: Firstly, we have developed various components for determining the daytime behaviour of a user (Sect. 2). Secondly, we have developed a component for recognising sleep architecture, i.e. the sequence and frequency of the various types of sleep stages in the course of a night (Sect. 3). The third subtask is to eventually identify correlations between daytime behaviour and sleep architecture (Sect. 4). This paper is a considerably extended and updated version of [8].

2 Recognition of Daytime Behaviour

The ability to generate meaningful suggestions for changing daytime behaviour to improve one's sleep very much depends on a detailed characterisation of a user's daytime behaviour. Our approach is based on two different kinds of characteristics: a user's activity during the day and a user's stress levels, i.e. if there are high-, medium- and low-level stress phases during the day, how long they last and at which times they occur. For measuring stress levels we use a body sensor and a smartphone as described in our previous work [9].

In the following we discuss how we have tackled the recognition of activities. We distinguish between the recognition of elementary activities (Sect. 2.1) and complex activities (Sect. 2.2). The latter is much more challenging and will therefore be discussed in more detail.

2.1 Detection of Elementary Activities

Elementary (or low-level) activities are either static or dynamic. *Static elementary activities* (such as standing, sitting, lying) correspond to *body postures*. Body postures can be reliably determined by a variety of sensors, resp. wearables on the market so that there is no need to develop any new components.

Dynamic elementary activities show a periodic movement pattern within a time interval of about one to ten seconds. Typical elementary activities are walking, running and cycling, but also dancing and vacuum-cleaning given the periodicity of the activity. Similarly, washing dishes could count as an elementary activity and perhaps also window cleaning depending on how it is done. In fact, the boundary between elementary and complex activities may at times be blurred.

In the literature there are many approaches that deal with the detection of elementary activities using accelerometers, either dedicated ones e.g. worn at the wrist or the upper arm, or ones that are integrated in a smartphone or a smartwatch. For this setting, recognition accuracies of more than 90% have been achieved – see e.g. [10,11]. Additional research for developing new algorithms is therefore not necessary, only an adaptation of existing algorithms to accommodate specific sensors might be necessary.

2.2 Detection of Complex Activities

As already mentioned, defining the concept of a complex activity and differentiating it from an elementary activity is not always easy. A complex activity can be said to be a composition of several low-level activities. It therefore does not show any periodic movement patterns within a timeframe of up to ten seconds as is typical of elementary activities. Based on this definition the following are examples of complex activities: preparing a meal, shopping, gardening. When it comes to learning classifiers for complex activities it becomes important that they are clearly defined, i.e. *sufficiently specific* and with *meaningful boundaries*.

Specificity means that a complex activity does not have too much variation. For example, gardening would be a too generic activity to learn because it can imply pruning roses, planting flowers, or mowing the lawn. All these activities would have a very different signature, which means that we need to subdivide gardening into all possible kinds of activities and then learn classifiers for each of these activities. Similarly, the activity of shopping is too generic. Shopping for groceries in a mall certainly has different movement patterns than doing this in a small shop where you stand at the counter and get served by a sales clerk. Furthermore, shopping for groceries is quite different than shopping for clothes where you may go into different stores, browse what is on offer and try on different clothes. Thus, definitions of complex activities for shopping would be: shopping for groceries in a self-service store, shopping for groceries in a serviced store, shopping for clothes, etc.

Meaningful boundaries means that it must be clearly defined with which kinds of low-level activities a complex activity starts and ends. For example, with what does a shopping activity begin? Is the drive or walk there already part of it? Does it end with putting away the groceries in the kitchen? In order to reduce the possible variation between different activity instances their definition should be such that only the characteristic part of it is covered. In the case of shopping this would mean that it should be defined as starting with entering the shop and ending with leaving it.

Learning classifiers for recognizing complex activities is much more difficult than for elementary activities because the movement patterns are less specific and show greater variation. As a consequence, more data to learn from is needed to make up for the greater variation.

Related Work. The task of learning strong classifiers for complex activities very much depends on using the proper features – as it is the case with all data analysis tasks. Consequently, a main focus of existing research is on determining which features to use. [12] experiments with several approaches that all use the

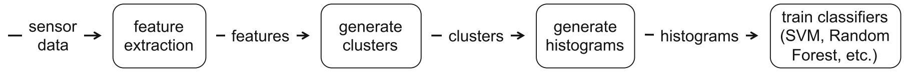

Fig. 2. Main steps for training a classifier for complex activities.

mean and variance of the acceleration signals of all three axes over a sliding window as the underlying basic features. The resulting feature vectors are then clustered using the k-means algorithm. Each cluster is labeled with the activity that occurs most often in the cluster, i.e. is most often associated with the feature values occurring in the cluster. With this approach the feature vectors are mapped to a set of discrete symbols. One of the approaches examined in [12] classifies a new data sample by assigning to it the label of the closest cluster center. Two other approaches build upon the generated clusters and compute histograms of cluster assignments over a sliding window on the input data. This window needs to be several times longer than the one for computing the features since a histogram aggregates the cluster assignments of several features. Each histogram is labeled with the activity that occurs most often in the window of samples that it covers. Classification is done using a nearest neighbor classifier on the histograms, resp. a support vector machine (SVM) with the histograms as features. The fourth approach described in [12] generates a Hidden Markov Model directly from the feature vectors derived from the input data. The best result of about 92% was achieved using the histogram approach with an SVM classifier.

The central idea of the first three approaches in [12] is to create a *vocabulary from the feature vectors* rather than use the feature vectors directly. This idea has been successfully applied by others as well, e.g. [13,14].

Bottom-up approaches such as [15,16] pursue a different approach: they identify simple activities first and then characterize complex activities as a composition of simple activities. To this end, [16] includes a preprocessing step that performs a segmentation into simple activities first. Afterwards histograms are generated to describe the distribution of the simple activities for each complex activity. Finally, features are extracted from the histograms which are then used for classification. Similarly, [15] uses the occurrence and sequence of simple activities (called 'micro-activities') to recognize complex activities.

A completely different approach is described in [17] which relies on background knowledge about the composition of complex activities as represented by an ontology. In addition to a concept hierarchy of activities, the ontology represents temporal relationships between the constituent parts of a complex activity. Classification then amounts to recognising simple activities from sensor data and employing terminological and temporal reasoning to identify the complex activity. The advantage is that due to background knowledge, the recognition of simple activities from sensor data need not to be as accurate as when it is the only source. The approach achieves an overall accuracy of about 88%.

Table 1. Complex activities considered.

Complex activity	Description	Training data (minutes)	Test data (minutes)
Gardening	Includes pruning trees as well as planting flowers	70	124
Grocery shopping	Driving to and from the mall by car, shopping in the mall, putting the groceries in the cupboard at home	57	114
Cooking	Washing and chopping vegetables, working at the stove, setting the table	22	57
Household chores	Includes vacuum cleaning, dusting, changing bed sheets	77	104
Workout in a fitness studio	Changing clothes, various exercises with breaks in between	65	143

Our Approach. The approach we have adopted is based on the generation of histograms of cluster assignments as has been described in [12] and explained above (see also Fig. 2). We experimented with different kinds of sensors, sensor placements, features, numbers of clusters into which the features are arranged, time windows for calculating the histograms as well as various classifiers. We worked with the following sensor placements:

- two MSR 145B[2] accelerometers – one at the right wrist and one at the left ankle (or vice versa), with a sampling frequency of 51.2 Hz,
- one MSR 145B at the wrist,
- the built-in sensor of a smartphone worn in a trouser pocket,
- smartphone and an MSR sensor at the wrist.

Differently from [12] we experimented with various features to find out which ones were most significant. Time domain features included mean, standard deviation, root mean square, and skewness, while frequency domain features included energy, entropy, and maximal frequency. These features were calculated for all three axes of all accelerometers. For each sensor we considered the norm as an additional feature, i.e. the absolute value of the mean acceleration, and in the case of using two MSR sensors, we added the correlation between the two sensors as a further feature.

Table 1 shows the complex activities that we have considered as well as the duration of recorded sensor data for training and testing the classifiers.

Each activity type was recorded and labeled by one person only, meaning that the learned classifiers were person-specific. Activity labeling as well as starting and stopping the recording of sensor data was done using a smartphone app.

[2] www.msr.ch.

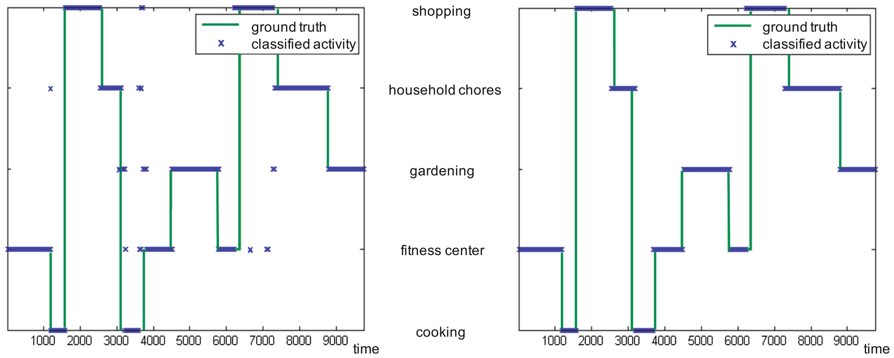

Fig. 3. The effect of smoothing: left side without, right side with smoothing.

The assignment of clusters to histograms was done in two different ways. *Hard assignments* put a cluster into one histogram only, namely the nearest one. *Soft assignments* put a cluster into the n nearest histograms, each assignment with a weight that corresponds to the distance and using a softmax function to calibrate the sum of the weights to 1. The results discussed below are based on $n = 3$. Our approach to recognizing complex activities is described in more detail in [18].

Discussion of Results. We achieved the best results with an SVM over 60 clusters (using soft assignments), a histogram time window of 225 samples and with two MSR sensors, one at the wrist and the other one at the ankle (87%). The second best result was achieved with one MSR sensor attached to the wrist (81%). Hard cluster assignments yielded less accurate results. A Random Forest classifier had only slightly less accuracy than the SVM.

Adding a *smoothing step* after classification increased the accuracy to 90–95% depending on the exact learning set-up. Smoothing implies looking at classifications left and right on the time axis and assigning the current data sample to the class that is predicted most often in the left and right neighbourhood. The strong effect of this kind of smoothing can be explained by the fact that misclassifications mostly occur at the boundaries of two activities (cf. Fig. 3). Compared to the findings reported in the literature (see discussion above) this is a very good result.

We also experimented with various combinations of features and found that mean and standard deviation give the best results. Combining them with other features such as skewness and root mean square actually reduced the accuracy. The combination of the frequency-based features of energy, entropy and maximal frequency led to similarly good results when using a smartphone only (78%) but gave far worse results for the MSR sensors.

The activity of grocery shopping was often confused with cooking because putting away the groceries in the cupboard is very similar to movements associated with cooking. Household chores and cooking were also often mixed up when using a smartphone as a sensor device, which is not as good at identifying hand and foot movements as an accelerometer at the wrist and/or at the ankle.

There are a few *lessons learned* from our experiments that will feed into our future research. Most important is a narrower definition of the complex activities to be recognised. For example, it is probably better to reduce the complex activity of grocery shopping to the activity within the store and leave out the drive to and from the shopping mall as well as putting away the groceries because it is too close to kitchen work. Similarly, the activity of gardening should be divided into more specific activities such as planting flowers, planting trees and pruning trees.

This will take us closer to the approach underlying [17] who use an ontology of complex activities and how they are constituted of simpler activities. We believe that adding this kind of background knowledge will help us to considerably improve recognition rates. We are also planning to add further types of input data, especially location, e.g. being indoors as opposed to being outdoors, and heart-rate to determine the intensity of an activity.

These improvements should not only increase recognition rates but, more importantly, allow us to learn accurate classifiers from less data. We would then be able to develop a smartphone app which allows users to train classifiers themselves for those activities from the underlying ontology that are most relevant to them. In this way, we could solve the problem that classifiers for complex activities are much more person-specific than classifiers for elementary activities [19], which means that pre-installed classifiers are less accurate than those trained by the users themselves.

3 Learning Sleep Stage Classifiers

For determining the effects of daytime behaviour on sleep architecture the SmartSleep project needed to develop classifiers for sleep stage recognition based on wearable sensors that can be used outside the sleep lab in a home setting. The following sections describe our approach, first characterising the kind of problem to be solved (Sect. 3.1), then explaining the experimental set-up (Sect. 3.2) followed by a description of our approach using *handcrafted features* (Sect. 3.3) and our approach based on features learned via a *deep belief network* (Sect. 3.4). A discussion of results is given in Sect. 3.5.

3.1 Recognition of Sleep Stages from Wearable Sensors

The automatic detection of sleep stages from sensor data is a goal that many researchers are currently pursuing. Most existing approaches work on the polysomnography (PSG) data generated in a sleep lab, i.e. EEG, EOG and EMG (see e.g. [20–22]). So far only very few papers have been published on detecting sleep stages from wearable sensors developed for the consumer market. Some of them use other consumer sensors as the ground truth rather than a clinical gold standard such as PSG against which they evaluate their systems and algorithms [23,24].

Among the few papers that have reported the use of sensors suited to a home setting, only a small fraction has actually validated their results against a clinical gold standard such as PSG or the Rechtschaffen and Kales method (R-K method). Automatic sleep stage recognition based on heart rate and body movement was investigated in [25] and the accuracy of their system compared with the R-K method. [26] discuss the detection of sleep and waking time by various motion sensors and compare them with PSG measurements taken in parallel. They were not concerned with the detection of different sleep stages, however.

For our SmartSleep project we could not use the sleep stage recognition services of any of the existing body sensors that offer sleep stage detection because the sleep stage recognition implemented has been shown to be rather unreliable. Many of them even have difficulty in distinguishing sleep from waking phases with sufficient accuracy [27]. These findings coincide with the results of our own experiments which compared two of those devices and found nearly no correlation between detected sleep stages at all. Therefore it was necessary to develop our own recognition algorithm.

Recognition algorithms are not handcrafted but obtained by learning a classifier for each sleep stage. For this we need *(a) appropriate input data* from which to learn the sleep stage classifiers, *(b) an appropriate learning algorithm*. The input data was provided by the clinical project partner who has taken measurements with our consumer sensors *in parallel to classical PSG*. Using data mining algorithms we were then able to correlate the sleep stages as recorded in the PSG hypnogram with specific patterns in the data from the consumer sensors. The patterns so identified can then be used to segment sensor data streams into sleep stages. The following section describes our experimental set-up in more detail.

3.2 Experimental Set-Up

We have been experimenting with several kinds of wearable sensors and finally focused on the following two:

- Zephyr BioHarness 3[3] chest strap with a reporting frequency of 1 Hz for the channels: heart rate, breathing rate, breathing rate amplitude, ECG amplitude as well as minimum and peak levels of the vertical, lateral and sagittal axes
- two MSR 145B[4] accelerometers, one at the wrist and one at the ankle, with a sampling frequency of 51.2 Hz – the same ones we used for activity detection (see Sect. 2.2)

These sensors were given to 19 healthy volunteers in addition to the usual PSG sensors in the sleep lab of the clinical project partner. For each person the sleep

[3] www.zephyranywhere.com.
[4] www.msr.ch.

stages ('Wake', 'REM', 'N1', 'N2', 'N3')[5] were labelled by experts according to the gold standard of the AASM classification[6]. This resulted in sensor data streams segmented into labelled sleep stages of 30 s each, from which the sleep stage classifiers were subsequently learned. After filtering out flawed measurements, e.g. due to incorrect sensor setups, we ended up with a total of 14,174 labelled segments.

An important preprocessing step involved the clipping of all the 30 s segments by 1.5 s at their start and their end to make up for possible misalignments between the PSG clock and the sensor clocks. Although they were always manually synchronized with each other at the beginning of each measurement, a slight offset of less than one second between the intervals was still possible. The clipping ensures that we are on the safe side and do not use sensor data across the boundary of two labelled PSG intervals.

We used the Weka libraries[7] implementation of a Random Forest classifier, an ensemble learning approach which has also been used by other researchers for learning sleep stage classifiers and has shown to be superior to an SVM ensemble by [28]. The data processing pipeline was implemented in Matlab in an object-oriented way: The classes and processing stages were inspired by the pipes and filter patterns described in [29]. This enabled us to set up new experiments in a fast and flexible way by appropriately combining data file readers, interpolation and data merging stages, filtering, feature construction and classification steps.

The quality of the learned classifiers not only depends on the chosen algorithm and its parameter settings but above all on the features being used. Especially in the case of learning from sensor data, identifying significant features is a critical and difficult task. We experimented with handcrafted features (see Fig. 4 and Sect. 3.3) as well as with unsupervised feature learning based on the deep learning paradigm (see Fig. 4 and Sect. 3.4).

3.3 Handcrafted Features

Finding significant features usually involves much experimentation, in particular in the case of sensor data streams. We did a literature review to identify features that worked for other researchers. We not only looked into handcrafted features used for recognising sleep stages (e.g. [30]) but also into features used for recognising activity types (cf. Sect. 2.2 and e.g. [11]). Based on the literature review, we decided to use the following functions to calculate the *features from the sensor raw data*:

- energy (sum of power at each frequency),
- sum over all values,
- root mean square of sensor channel values,
- skewness (asymmetry of the probability distribution relative to its mean),

[5] REM corresponds to rapid eye movement sleep, while N1 to N3 correspond to progressively deeper stages of sleep, N1 standing for light sleep, N3 for deep sleep.

[6] www.esst.org/adds/ICSD.pdf.

[7] weka.wikispaces.com.

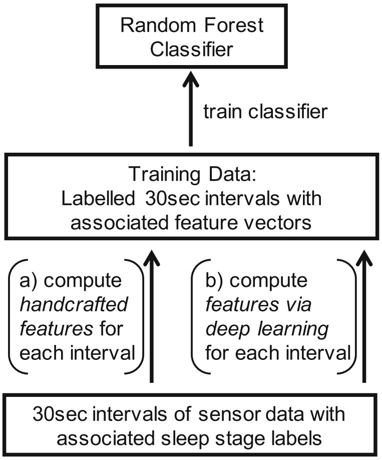

Fig. 4. Feature generation and classification pipeline.

– standard deviation,
– vector norm (length of vector of sensor channel values).

We made use of all those features but more systematic experimentation will be needed to find out if a combination of a subset gives better results, as was the case with recognising complex activities (see Sect. 2.2).

The handcrafted features are functions which aggregate the raw data of each 30 s window and each sensor channel into a value. For the ten channels of the Zephyr chest strap this results in a feature vector of 60 components per 30 s sleep stage event, and for the six channels of the two MSR accelerometers in a feature vector of 36 components. With these features three Random Forest classifiers of 99 trees were learned – one for the two MSR sensors, one for the Zephyr chest strap, and one for the two MSR sensors together with the Zephyr. For each classifier we determined the classification accuracy based on a *tenfold cross-validation*.

With the two MSR accelerometers we achieved an overall accuracy of 84.5% (see Table 2), while the results of the Zephyr chest strap were around 70%. One would have expected the chest strap, which delivers heart rate and breathing rate in addition to accelerometer data (although measured only at the chest), to be superior to accelerometer data only. However, it turned out that using chest straps such as the Zephyr for sleep stage recognition has several drawbacks: First, we experienced many dropped readings due to the electrodes losing contact when a person moved. We therefore had to eliminate a significant proportion of the sensor data stream, which reduced the number of learning examples. Second, we not only missed measurements but also got many readings with artifacts. We filtered out measurements with obvious artifacts but in all likelihood we missed quite a few artifacts, which then introduced noise into the input data. An additional problem specific to the Zephyr was that in its data streaming set-up heart rate and breathing rates were delivered only every second, although the sensor works internally with 250 Hz for the ECG signal. Further, for the built-in accelerometer we only obtained the minimum and peak values of the last second. We therefore stopped using a chest strap in our further experiments.

The confusion matrix in Table 2 shows that the worst classification results are for sleep stage N1, it mostly being confused with N2. This is surprising because a human expert can quite easily distinguish N1 from N2. A possible explanation is that we simply did not have enough data to learn from since the N1 stage occurs quite rarely (only 2–5% of total sleep time). Since the distinction between N1 and N2 is not of that much importance we learned an alternative classifier for the sleep stages N1 and N2 combined. The resulting confusion matrix is shown in Table 3. A more detailed discussion of the results can be found in Sect. 3.5.

Table 2. Confusion matrix: two MSR accelerometers, handcrafted features.

Instances:		14174			
Correctly Classified:		11973	84.5%		
			Predicted		
%	REM	Wake	N1	N2	N3
REM	**89.6**	1.1	2.8	6.3	0
Wake	1.1	**86.8**	6.1	4.4	1.5
N1	10.1	8.0	**37.3**	42.5	2.1
N2	2.1	0.8	3.1	**90.5**	3.5
N3	0	1.0	0.5	8.1	**90.2**

Table 3. Confusion matrix: two MSR, handcrafted features, N1 and N2 combined.

Instances:		14174		
Correctly Classified:		12764	90%	
		Predicted		
%	REM	Wake	N1+N2	N3
REM	**87.0**	1.0	11.8	0
Wake	0.9	**84.4**	13.7	1.1
N1+N2	3.4	1.7	**92.3**	2.6
N3	0	0.6	9.1	**90.2**

3.4 Unsupervised Feature Learning Using a Deep Belief Network

Feature engineering is a labour-intensive task. Inspired by the recent enthusiasm about deep learning [31] we decided to find out how learning a Random Forest classifier using handcrafted features related to one using features learned via *deep learning*. Especially in the context of learning sleep stage classifiers, [20] have already shown that unsupervised feature learning with deep learning is promising. We followed a similar approach and derived *higher-order features*

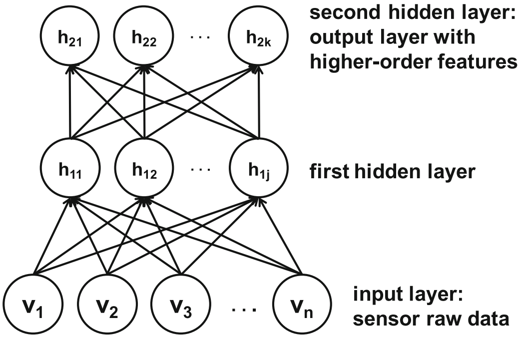

Fig. 5. A deep belief network of two stacked Restricted Boltzmann Machines (from [8]).

from the raw data of the sensors by applying a deep belief network (DBN) built from stacked Restricted Boltzmann Machines (RBM) – cf. Fig. 5. These higher-order features reflect significant patterns in the underlying raw data and are therefore expected to be well suited as features for a classifier.

We used DeeBNet[8], an open source Deep Belief Network implementation in Matlab [32]. For the reasons outlined in the previous section we only considered the MSR sensors. The input vector to the DBN, i.e. the raw sensor data for each 30 s sleep stage event, was constructed as follows: For each MSR accelerometers we have 3 channels with an interpolated sampling frequency of 20 Hz. This amounts to 3600 components in the input vector for the two MSR together.

For the approximation of the log-likelihood gradient the one-step contrastive divergence (CD) method as proposed by [33,34] was applied. As part of future fine-tunings we might experiment with other approximation methods and parameters for the RBMs in the DBN.

Configuring a DBN and finding a good topology requires both expertise and experimentation [35]. We experimented with various numbers and sizes of hidden layers and also used different numbers of learning epochs. It turned out that the results in terms of classifier accuracy did not change significantly, except for the number of units at the output layer which correspond to the number of features learned. In order to avoid overfitting we need to enforce a sufficient amount of generalisation by setting the number of features to be significantly smaller than the number of input units (in our case 3600). We experimented with various settings and found 200 features to give the best results.

The accuracy of the learned Random Forest classifier based on the features generated by the DBN is shown in Table 4. We also did a run with sleep stages N1 and N2 combined: see Table 5.

[8] ceit.aut.ac.ir/~keyvanrad/DeeBNet%20Toolbox.html.

Table 4. Confusion matrix: two MSR accelerometers, DBN-created features.

Layer 1: 886 hidden units, 150 epochs					
Layer 2: 443 hidden units, 150 epochs					
Layer 3: 200 hidden units, 150 epochs					
Instances:		14174			
Correctly Classified:		11290	79.7%		
			Predicted		
%	REM	Wake	N1	N2	N3
REM	**82.6**	0.8	4.7	11.2	0.7
Wake	2.3	**79.6**	6.5	8.9	2.8
N1	12.4	7.5	**34.5**	42.0	3.6
N2	3.2	0.8	3.7	**86.6**	5.7
N3	0	1.7	0.7	11.5	**85.7**

Table 5. Confusion matrix: two MSR, DBN-created features, N1 and N2 combined.

Layer 1: 886 hidden units, 150 epochs				
Layer 2: 443 hidden units, 150 epochs				
Layer 3: 200 hidden units, 150 epochs				
Instances:		14174		
Correctly Classified:		11788	83.2%	
			Predicted	
%	REM	Wake	N1+N2	N3
REM	**78.5**	0.7	19.9	0.9
Wake	2.2	**72.6**	22.9	2.2
N1+N2	5.0	1.8	**87.5**	5.7
N3	0	1.2	16.2	**82.2**

3.5 Discussion of Results

Our results are significantly better than those reported by other researchers who also used sensors suitable for home settings. For example, [25] achieved a mean of correctly classified sleep stages of 56.2% when comparing their approach against the R-K method with 5 distinct sleep stages. For distinguishing between sleep and waking time [26] presented a classifier with a mean number of correct classifications of approximately 85% against PSG measurements. Our best result for identifying waking time against any of the sleep stages is 86.8% (see Table 2). [36] used a wrist-worn accelerometer to detect sleep and wake phases and reported a precision of 79% for detecting sleep and 75% for wake phases against PSG measurements taken in parallel.

The work reported in [23] presented a classifier and evaluated it against another consumer device as a reference point and achieved 63.7% of correctly classified REM stages and 60% of correctly classified N3 stages against that device. [24] presented a classifier that was compared against two other consumer devices and achieved 80.5% when distinguishing REM vs. non-REM stages and 89.3% when distinguishing sleep from waking times.

The recently published work of Biswal et al. [37] is worth mentioning although it does not use consumer devices but aims at developing a clinical decision support system that suggests sleep labels to human sleep stage annotators with the aim to reduce the time needed for the annotation and increase quality. The system makes use of the EEG data and was trained on a PSG database comprising the data from the impressive number of 10,000 patients. Different to our approach the authors used handcrafted features and deep learning to train the classifier. They experimented with various types of neural networks and found that a recurrent neural network worked best, achieving an overall classification accuracy of 86%. At first sight it is surprising that the authors did not achieve a much higher accuracy, but given the fact that the classifier was learned from data from all kinds of persons, many of which probably with sleep disorders, instead of using data from healthy persons only, this is a remarkable result.

Although our results using features generated by a deep learning approach look promising, we still get better results when using handcrafted features. We expect that the results using deep learning will improve when we have more learning data available because the experience of other researchers show that deep learning needs lots of input data, which we currently do not have. Secondly, there are other, more sophisticated types of deep learning architectures, which will might give better results, using for example convolutional or recurrent neural networks [38]. Unfortunately, they need even more input data than our approach based on Restricted Boltzmann machines. When we have more measurements available we will look into these issues.

We also looked at the recognition rates for individual persons and how much they vary. To this end, we trained classifiers without the data from preselected persons and then classified the sensor data of those individuals using the classifier. We did this for 14 persons for the combination of the MSR and Zephyr sensors. For the 14 persons four recognition rates were above 80%, six were between 70% and 80%, three between 60% and 70% and one below that. This shows that while average recognition rates are high, there is a high deviation of accuracy between individual persons. We are still collecting more measurements and will see if the deviation decreases with the amount of learning input.

4 Correlating Daytime Behaviour with Sleep Architecture

Using the recognition of daytime behaviour as described in Sect. 2 and the sleep stages as described in Sect. 3 the final task is to detect correlations between the two (cf. Fig. 1). To this end we first need to define the features to be used when looking for correlations. As has been discussed in Sect. 2, daytime behaviour is characterised by elementary and complex activities as well as stress levels during the day. Relevant features for describing activities are the type of the activity (e.g. walking, cooking), duration, time of day (morning, noon, afternoon, evening), location (indoors vs. outdoors), and intensity as measured by heart rate. Relevant features for characterising stress are its degree (i.e. low, medium, high) and the duration and time of day associated with each degree.

The following dimensions are relevant for assessing sleep architecture: efficiency (relation between total time of sleep to time in bed), latency (the time it takes to fall asleep), consistency (regular bedtimes and wake times), percentage of deep sleep and percentage of REM sleep. These are the *target variables* to be predicted by daytime behaviour. As the target variables for a specific person we take those that differ significantly from what are regarded as average values, which, of course, changes with age [39].

To be able to learn meaningful correlations between daytime behaviour and the target values we need to *aggregate and generalise the features for daytime behaviour*. This reduces the high dimensionality which would result when considering all combinations of individual features. A possible approach is to aggregate the activities into a bar chart where each bar stands for the duration of a certain kind of activity. The bars could then serve as features in a correlation instead of the occurrence and duration of each single activity. This feature can be refined by creating bar charts for different times during the day. In the same way, a bar chart based on the intensity of activities can be generated.

An underlying ontology of activities could be used to derive other kinds of feature aggregations. Activities could be grouped into indoor and outdoor activities, into social activities and activities users do on their own, e.g. reading. We could also ask users to augment the ontology by stating which activities they find pleasant and which ones unpleasant and then calculate the ratio between the two. We will refine these ideas further and then find out which features work best in real-life settings.

5 Outlook

This paper presents the results of our project SmartSleep which aimed at laying the foundation for a smartphone app giving people individual advice on how to change their behaviour to improve their sleep. The advice is based on correlations between behaviour during the day and sleep architecture. The project therefore focused on the two subtasks of determining daytime behaviour as well as recognising sleep stages, both by using wearable sensors. To tackle the ultimate task of finding correlations to generate advice from, we have developed preliminary data analysis algorithms, which will be implemented and evaluated in real-life settings. This follow-up project will focus more on the actual development of the smartphone app and the associated backend algorithms.

Determining daytime behaviour involves the recognition of a user's activities as well as the stress levels during the day. While stress level detection had been developed in a former project [9], the most challenging part was to detect complex activities such as gardening, cooking, or household chores. We obtained the best results with two accelerometers, one at the wrist and the other at the ankle, achieving an accuracy of 87% and after a subsequent smoothing step of up to 95%. Future work concerning the activity detection subtask will focus on taking different kinds of sensor data into account, in particular *heart rate* and *location*, as well as *background knowledge* in the form of an ontology of complex activities that will comprise a concept hierarchy of activities and a representation of how activities are composed of constituent activities. With these measures we expect to increase the learning rate so that less input is needed, thus enabling users to train the relevant classifiers themselves without having to provide too much annotated data.

Determining sleep stages for healthy people worked surprisingly well with the same two accelerometers that we used for activity detection – one at the wrist and one at the ankle. With these sensors we achieved an overall accuracy of 84.5% (Table 2). The weakest classification result was for the stage N1 which was often confused with N2. If we do not distinguish between N1 and N2 but combine them into one stage the overall accuracy increases to 90% (Table 3).

To further improve sleep stage classification an additional sensor for vital signs is needed. Because of our disappointing experience with the chest strap, we looked for alternatives. While there are other chest straps we could use, they would also have the problem of misreadings and artifacts because movement in bed often causes a loss of electrode contact. We have therefore begun to experiment with a new body sensor from our project partner Biovotion which is positioned at the upper arm. Apart from sensors for measuring skin temperature and an accelerometer the device includes three opto-electronic sensors for different wavelengths which measure the absorption by the skin tissue. We are using the raw signals from the optical sensors as well as the accelerometer data as input to our deep learning framework to learn higher-order features from them. The opto-electronic sensor data is ideal for deep learning since the optical signals contain a lot of information on vital signs, e.g. heart rate and oxygen saturation can be derived from it. First results are encouraging because they show recognition rates of as high as 77% for N2, 84% for N3 and of 77% for REM even for a small amount of learning data of 4069 labeled sleep stages. We are currently collecting more data and expect to achieve significantly higher recognition rates with the Biovotion sensor. Besides the inclusion of vital data we expect further accuracy improvements to be due to having more learning input, using a more powerful deep learning architecture (e.g. based on a recurrent neural net), and – most importantly – from considering transition probabilities between sleep phases.

In the future we might invest the effort to have the sleep stage labels in our learning input be created by two experts who have to come to an agreement on all those labels where they differ. This increase in data quality might prove important as it is known that the inter-rater agreement for annotating sleep stages is between 65–75% [40]. It is pointless trying to achieve recognition rates of 90% on data that is only 75% consistent.

The sleep stage classifiers we have learned so far are for healthy individuals but we will also learn further classifiers for patients with specific diagnoses and will investigate in which cases classifiers for healthy people can be applied to people with certain medical diagnoses and in which cases this does not work.

Finally, we are planning to integrate the results of the SmartSleep project into our framework of behavioural change support systems [41] as we are convinced that giving personalised advice can contribute considerably to behavioural change.

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ActiveAdvice: A Multi-stakeholder Perspective to Understand Functional Requirements of an Online Advice Platform for AAL Products and Services

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Abstract. For the last 10 years, ageing well in the community has become a key concern of the European Union and its member states. Action plans as well as distinct programs such as the Ambient Assisted Living (AAL) Joint Programme are evidence of this engagement. Since then, many AAL products and services have been developed and implemented in the European market. Up to now, however, access to, and the availability of these solutions is difficult, and the information on their use is scarce. ActiveAdvice, an AAL EU-funded project aims to develop an online platform which offers both information on AAL solutions as well as advice to end users. This paper discusses the application of a multi-stakeholder perspective approach. It discusses the user-centered development and reflects on the establishment of AAL ecosystems and the functional requirements of the ActiveAdvice platform. It includes an extended methodological framework, which explains conclusively the ActiveAdvice stakeholders' identification process and the user-centered requirements analysis, built on 38 semi-structured interviews with three stakeholder groups – consumers, businesses and governments. The integration of different stakeholders in the development and implementation of AAL solutions is a necessity as well as a challenge. This holds also true for the development of the ActiveAdvice platform.

Keywords: Ambient Assisted Living · Multi-stakeholder perspective User-centered design · Online advice platform

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1 Introduction

Research on ageing suggests that older adults would prefer to age independently and in their private homes as long as possible [1, 2]. Similarly, family members and other informal caregivers have shown a preference to provide care in familiar environments [1, 2]. Nonetheless, with regards to their health status, ability to perform the activities and instrumental activities of daily living (ADLs and IADLs) autonomously, socioeconomic and family situations, interests and capabilities, older adults constitute a highly heterogeneous group. This means that new approaches and concepts are required to cope with the great variety of needs these older adults have. In addition, throughout Europe, the number of caregivers – both on a professional, as well as informal level – is declining [3]. Demographic, social and cultural trends causing this development include: (i) the increasing proportion, in the EU population structure, of the old and "oldest old" individuals as opposed to a decreasing proportion of children/younger adults; (ii) the rise in the female labor market participation (since informal caregivers are mostly women of working age); and (iii) a trend for family organization in small units, particularly in the urbanized context [3]. Due to the above, several pan-European initiatives have been launched to promote and foster innovations, which would allow sustainable, financially affordable, and life enhancing solutions [4, 5]. In 2007, the European Union approved the action plan "Ageing Well in the Information Society" [2]. This plan also was the stimulus for the creation of the Ambient Assisted Living Joint Programme (AAL JP, formerly Ambient Assisted Living Joint Programme) in 2008. The Joint Programme combines social, technological and business aspects and aims to develop new models of service delivery and care [5]. The AAL concept corresponds to a new paradigm, which builds on the potential of ubiquitous ICT-devices and new forms of interaction to improve the quality of life of older adults as well as their autonomy, security, health and social integration [6].

Hence, AAL products and services currently tackle multiple dimensions of older adults' lives. Proposals to categorize AAL products and services have been advanced, which is the case of TAALXONOMY [7], a classification system taking into account the international definitions (e.g. WHO, OECD), initiatives (e.g. BRAID, EIP-AHA) and standards (e.g. ISO 9999). According to this framework, AAL products and services can be categorized according to three levels: (i) scope of application (Health & Care; Living & Buildings; Safety & Security; Mobility & Transport; Work & Training; Vitality & Abilities; Leisure & Culture; Information & Communication); (ii) field of application; and (iii) use cases [7]. Nevertheless, numerous constraints have been found in the implementation of AAL. These are associated with a lack of user-centered design and low adherence by end users [8–10] as well as with business sustainability problems [11]. In addition, the absence of interoperability between systems [11–13] as well as the limited evidence on interactions between technology and society, on the impact of technologies and their cost-effectiveness have been identified as constraints [11, 14]. Another constraint considered as one of the most challenging is the requisite of involving and engaging, from the earliest moment in the development process, multiple stakeholders with their heterogeneous competencies, interests in the technological developments and needs. The different interests and agendas of the various AAL stakeholders are likely to affect the technology uptake [15–19]. Therefore, the close involvement of different stakeholders requires researchers to find successful strategies to motivate them to participate, to understand them and to finally translate their inputs into the proper requirements [20, 21].

The EU-funded ActiveAdvice project aims to support the promotion of AAL services and products, which must be context and situation-aware, pro-active, and adaptive [22]. ActiveAdvice is intended to set up a European-wide advisory and decision support platform that brings together the broad range of available AAL products, services and experts. It intends to include end-users from the beginning to the moment of its launch and beyond. The project is driven by a design that depicts a holistic representation of a highly complex AAL stakeholder ecosystem. Therefore, the project applies a multi-stakeholder perspective, and, by doing so, attempts to support the collaboration and co-operation among stakeholders towards active ageing and e-inclusion of older adults' needs.

This paper discusses a multi-stakeholder perspective and its methodological implications for the ActiveAdvice EU-funded project. The results presented are based on an extended narrative literature analysis but mainly summarize the key insights from a user requirements analysis, underlying the project. The paper follows the previous publication of preliminary findings in the paper "*A Multi-Perspective View on AAL Stakeholders' Needs: A User-centred Requirement Analysis for the ActiveAdvice European Project*" [23], which was presented at the ICT4AWE 2017 Conference.

2 Conceptual Considerations

It is frequently reported that many AAL products and services have been developed without taking the stakeholders' interests and needs into consideration [24]. AAL projects too often reflect a more "traditional" techno-centric approach. The ActiveAdvice project intended to minimize this gap by looking at how to best identify the interests of different AAL stakeholders (participatory approach), develop an online platform that regards social components as well as to recognize different needs and motivations (socio-technical approach and inclusive design), and take in consideration the stakeholders' contexts (information ecologies) [25, 26]. In the AAL field, attempts to develop online platforms to better support older adults and their relatives as well as to better integrate them very often lack to conceptualize a healthcare ecosystem. The latter is a rather complex theoretical construct that involves many different stakeholders, with diverse interests, needs and capabilities. Hereinafter, three key concerns of importance for the ActiveAdvice project are discussed in more detail: (i) the multi-stakeholder perspective, (ii) the user-centered development, and (iii) the implications of an AAL ecosystem.

2.1 Applying a Multi-stakeholder Perspective

Stakeholders, broadly defined, are conceived as "any group or individual who can affect or is affected by the achievement of the organization's objectives" [27, p. 46]. Notwithstanding, a wide view of the concept might mean that virtually anyone can be considered a stakeholder and the concept can lose its value. On the other hand, a narrower approach considers stakeholders as "those groups without whose support, the business would cease to be viable" [27, p. 46]. In the context of the ActiveAdvice project, and, rephrasing the AAL Association's (2014) definition of "stakeholders", those are understood as "(A)all the parties looking for information related to ICT and Ageing well", and wanting to use the ActiveAdvice software solution and the advisory network to gain advice, and more knowledge on existing solutions and on research outcomes; "The stakeholders can be divided into several interrelated groups", "each with their own needs and specific angle of approach towards the information" [28, p. 1]. Since in the context of the ActiveAdvice project, stakeholders are at the same time end users of the platform, the terms 'stakeholders' and 'end user' are used in this knowledge base indiscriminately.

Older adults have been identified as the main stakeholders of AAL products and services. However, there are also other stakeholder groups for AAL frequently pointed out in literature, such as relatives and informal caregivers, formal caregivers, health operators, healthcare professionals, medical specialists including GPs, community nurses, occupational therapists, physiotherapists, and consultants [15, 16, 24, 29–31]. Besides, national and regional governments, local authorities and councils on the one hand, and AAL solutions producing companies or enterprises supplying the devices on the other hand, act as stakeholders. In a broader sense, also technology designers and developers, engineers and researchers, as well as insurance companies are to be considered stakeholders [15, 16, 24, 32–39]. Proposals to cluster this multitude of AAL stakeholders or end users into primary, secondary, tertiary and even quaternary are advanced in literature [40–42]. In 1995, Clarkson [40, p. 106] for instance classified primary and secondary stakeholders. The first group is considered responsible for a company including shareholders and investors but also suppliers, employees, customers as well as the governments and communities whereas in contrast the second is influential but only involved in everyday business activities on a limited basis, "they are not engaged in transactions with the corporation and are not essential for its survival" [40, p. 107]. Any clustering of end users, be it primary to quaternary or primary to secondary stakeholders, however, is not straightforward, since it depends on the AAL solution [42]. Besides the clustering, it is even more important how relevant stakeholders interact with each other. This interaction and its intensity influences the success and guarantees the creation of value [27, 43], e.g. organizing and implementing a proper safety and security device in an older adult's household. So far, therefore, the multi-stakeholder perspective has been a challenge in the AAL context. It is not always straightforward to find and accommodate all stakeholders' interests without trading off one against another [44].

Predominantly, ageing in place is only socially and collaboratively accomplished or "co-produced" by the efforts of all stakeholders [45]. The ActiveAdvice project attempts to address this challenge and consistently applies a multi-stakeholder perspective, combining the views of different stakeholders, namely consumers – here considered older adults and their relatives and/or informal caregivers - , business representatives and government representatives, from a very early stage of the process. As will be shown (see Methodology), stakeholders in this context are clustered into three groups and nine subgroups.

2.2 UCD and Participatory Development of AAL Technologies

An integrated development approach results in a culture of participation and engagement, which promotes higher levels of stakeholders' influence and empowerment as well as an enhanced sustainability of assistive technologies [20, 21, 26, 39]. It is widely agreed that both user-centered design (UCD) and participatory design (PD) are meaningful approaches in developing AAL solutions [46–48]. The notion of UCD means that users' opinions are crucial, starting with the exploration of initial requirements up to the moment of the assessment of products and services [20]. In turn, participatory design assumes that, in its more meaningful form, end users actively share roles and responsibilities in the decision-making process. However, in solutions' development, insufficiently applied UCD and PD is still observed [48, 49].

Experts from diverse backgrounds are usually those who determine by and large the decision-making process regarding the concept, design and development, with end users being involved only in an advanced stage, which means that systems' conceptualization is not built into users' experiences or mental models [21]. This observation was concluded from a systematic literature review, in which existing AAL solutions appear to be rather built on the available technology than on end users' needs, attributes, consequences and values [24]. More recently, AAL projects are characterized, however, by the fact that older adults, as typically the primary end users, are integrated in the development from a very early stage in the project. Whilst this inclusion of older adults is a positive development in the design of AAL technologies, other stakeholders' needs still are very rarely considered [50]. A growing number of studies, therefore, have more recently emphasized the importance of a paradigm shift towards a more participatory development of AAL technologies, which would more frequently open the design process to various stakeholders, making it a collaborative effort. This would assure a faster diffusion of user-relevant technologies [26, 51, 52]. This is also supported by a recent research evaluating a web service developed in accordance with the Web Content Accessibility Guidelines (WCAG2.0) and the ISO 9241 standards family. The case study highlights problems with system usability and accessibility, when end users were only involved in trial of the new service, yet mostly excluded from the conceptual development of it [37].

The ActiveAdvice project puts emphasis on the premises of the UCD and the PD. Considering this, four theoretical approaches for the design of the online advisory platform are integrated: (i) the socio-technical approach; (ii) the participatory approach; (iii) the inclusive design, and (iv) the information ecologies [25, 26]. In all approaches, end users are participating in the decision-making at all stages of the design process and their different needs, backgrounds and capacities are taken into consideration. Moreover, in this process, technical and social components co-operate and co-evolve

2.3 AAL Stakeholder Ecosystem

At a European level, concerns were expressed about the lack of suitable collaboration and co-operation among stakeholders towards the active ageing and e-inclusion of older adults' needs [53]. It was stressed that, so far, in most AAL product and service developments, the entirety of AAL ecosystem has been somehow neglected [24]. In a recent systematic literature review, it has been found that solutions take "patients" (including older adults) and "physicians" much more into account, thereby not involving other stakeholders [24]. Another recent study in the Austrian AAL community shows that a comprehensive view on the involvement of different stakeholders in AAL projects is still missing; and while primary end-users are usually involved in both requirements definition and evaluation, other stakeholders, e.g. public institutions, are mostly left out [54].

An AAL ecosystem is indeed a rather complex entity. It integrates a diversity of stakeholders, each with different value systems, interests and capacities. Older adults, for example, might seek to increase their quality of life, whereas businesses might want to sell their products; representatives of local authorities might seek to guide their clientele towards appropriate solutions. An AAL stakeholder ecosystem is not the result of the many different bilateral relationships of e.g. buyers and sellers, caretakers and caregivers. Rather it is a collaborative system that describes a community of interconnected and interacting entities – across various different stakeholder groups, with the purpose of providing care and assistance to older adults and their caregivers. The latter are also members of this complex socio-technical ecosystem; they can be partners to developers and businesses [55]. By integrating a diversity of actors, by better understanding their needs and by improving the development and implementation in shortening the time both for the development and the time to market and reduce costs, AAL ecosystems form a hybrid value chain [56]. The analysis of this value chain can provide interesting economic insights into the stakeholders' commercial motivation inside and towards the ecosystem.

This rationale provides a promising framework for the ActiveAdvice project. In an ActiveAdvice ecosystem, stakeholders with very different value concepts meet: whereas older adults might seek to exchange their experiences with AAL products, the interest of AAL businesses is probably in gathering information on their potential customers. The public sector, in general, might be interested in building-up a health ecosystem for a distinct clientele. All this is taken into consideration as the project applies a multi-stakeholder perspective, which guarantees the stakeholders' integration as users of the platform, from the beginning and thereafter.

3 Methodology

The ActiveAdvice project aims to raise public awareness of AAL solutions and provide comprehensive and comparable information for different stakeholder groups. Therefore, the early integration of all potential stakeholder groups as future users, contributors and promoters had to be accomplished. Yet, the challenge was to identify the stakeholders most relevant for the ActiveAdvice platform development in the first place and then learn about their needs, interests, and motivations to use or contribute to the platform. A two-fold methodological design was applied.

In phase one, firstly, a narrative literature review to gather comprehensive information on the needs, requirements, motivations and deterrents for primary, secondary and tertiary users of AAL solutions was carried out. Secondly, in a use case generation and analysis approach, end user requirements were tackled. The aim was to illustrate decision-making processes regarding the search and selection of AAL solutions as well as the prospective use of the ActiveAdvice platform. Based on these two analyses, the ActiveAdvice stakeholders were identified, characterized and segmented. Clearly defined stakeholders were then summarized in a stakeholder map.

In the second phase, semi-structured requirements interviews were carried out. It was the aim to get to know the identified ActiveAdvice stakeholders' motivations in using ICT in general and social media in particular, to learn about challenges in accessing AAL information and when using AAL products and services. The interviewees were invited to discuss situations in which ActiveAdvice could support them the most. Furthermore, the interviews helped to clarify, whether and in which form the different stakeholder groups would pro-actively contribute to the platform in giving feedback on products. Based on these interviews, the functional requirements for the ActiveAdvice platform were identified.

3.1 Get to Know ActiveAdvice Stakeholders: Narrative Literature Review and Use Case Generation

Narrative Literature Review [57]. This was carried out as a first step to identify AAL relevant stakeholders to provide a broader coverage of the topic at stake. It was organized in three steps: (i) review planning, with the definition of research objectives, key-words and databases, as well as inclusion and exclusion criteria; (ii) performing the review, by carrying out the paper gathering and subsequent selection (applying the inclusion and exclusion criteria); and (iii) reviewing the documentation, with a qualitative summarization of the search results. For step one, a broad set of keywords and concepts were identified. It was followed by a preliminary screening of papers on AAL and stakeholder issues in general. Some of the keywords were kept fixed in the complete set of queries, namely Ambient Assisted Living, Active Assisted Living technology, Ambient Assistive, Telehealth and Telecare. The defined keywords were then searched in selected academic databases (e.g. Emerald Insight, Web of Science, EBSCOhost) and grey databases (e.g. Google Scholar). Publications by multilateral European and international organizations (e.g. the European Commission, WHO) were also searched and considered, if relevant. The search was narrowed down to publications not older than 2007. After a multistage filtering phase, 79 papers were selected for further analysis: its contents were categorized by themes, using therefore the qualitative method of thematic coding. The literature findings supported the establishment and segmentation of the project end users. Three main stakeholder groups have been identified: consumers (AAL2C), businesses (AAL2B), and governments (AAL2G). These three groups were further divided into nine sub-groups, as presented in Table 1.

Table 1. AAL stakeholder groups and sub-groups.

ActiveAdvice Primary stakeholders	
C1	Older adults aged between 55 to 70 years old, characterized by being active and autonomous. Includes older adults who decided to invest in a new home, usually in a smaller housing unit, and/or who wish to think ahead and adapt the house for an upcoming chronic illnesses and future loss of autonomy. Individuals within this group should be computer literate and be able to access information online

(*continued*)

Table 1. (*continued*)

C2	Older adults who are facing loss of autonomy and wish to live longer at home, therefore avoiding/postponing institutionalization. They are forced to look for solutions that enable them to improve their quality of life without leaving home. These adults are not necessarily literate in informatics and are not necessarily able to access information online. However, they must be able to do it with caregiver's support
C3	Relatives and/or informal caregivers of older adults who wish to help and assist their relative/the older adult they care for. This can be because of effective loss of autonomy (therefore forced to find a solution), but also to prevent further degradation, loss of functionality and autonomy (prevention)
ActiveAdvice Secondary Stakeholders	
B1	Suppliers of AAL solutions (products, services or a combination)
B2	Suppliers of services – consultancy services to older adults and their families – that could take a role as "active advisor" in the field of AAL and the ActiveAdvice ecosystem
ActiveAdvice Tertiary Stakeholders	
G1	Suppliers of services or solutions. This can be under normal market conditions (e.g. a provision of home assistance services), or under subsidized schemes for specific target groups
G2	Suppliers of services assessing needs of older adults and directing them towards the right solution or service. This segment could also play a role as "active advisor"
G3	Policy makers at local, regional and national levels, linked to ageing, living longer at home, health services and homecare services
G4	Public Services, senior organizations, interest groups, care cooperatives with governmental support

The older adults' segmentation is based on the interlinkage of the following factors: (i) chronological age; (ii) life course events; (iii) health and functionality status; (iv) relationship with ICT (particularly internet use); and (v) AAL related needs and desires. Since literature has shown that relatives are often the decision-makers or facilitators regarding the acquisition of AAL products and services, they are considered as a third segment as "indirect consumers". Businesses were segmented into two subgroups, the first including suppliers of AAL solutions (products, services or a combination) and the second referring to businesses which offer advisory services and could take a role as "active advisors" in the AAL field. Similarly, the "governments" target audience was segmented: first, differentiating between institutions, which are aimed at supplying services or solutions to older adults from policy and decision-makers, who design policies at several levels (local, regional and national); second, by distinguishing between organizations that only supply services or solutions to older adults, from those that also provide advisory services, similar to the segmentation established for businesses. Moreover, an additional stakeholder group was identified and integrated into "G4": public services, senior organizations, interest groups, and care cooperatives. It is noteworthy that during the data collection, it was noticed that some participants reunited criteria to cluster in more than one subgroup (e.g. older adults who simultaneously assist a relative).

Use Case Scenarios [57]. A use case scenario describes a real-world example, a narrative, of how people or organizations, a user, e.g. an older adult, interact with a system being designed to achieve a particular goal. Use cases represents descriptions of single steps, events, and actions that occur during an interaction.

Use cases within the ActiveAdvice project facilitate the illustration of the decision-making processes regarding the search and selection of AAL products and services as well as the learning about the prospective use of the ActiveAdvice platform. Four scenarios, two based on real life experiences and two hypothetical scenarios, were developed. From the four use cases derived, two concerned the requirements of primary stakeholders, i.e. older adults, while one use case targeted secondary, and another tertiary stakeholders.

The following exemplified use case illustrates what it takes to find a product or service that supports an older adult living alone. This is an example of a decision-making process around the purchase of a telecare service (pendant alarm) for an 82-year-old woman who lives alone in the UK. Table 2 provides information about the timeline, actors involved and steps taken.

Table 2. Decision making process: looking for a pendant alarm.

Actors	Process - steps	Time
Daughter	Encouraged mum to get a pendant alarm	January 2016
Mum	Speak to occupational therapists	February 2016
Occupational Therapist	Advice to use “Medicare” – council service, but this has a long waiting list	February 2016
Council Website	Use “Age UK” service or “Magenta” (local housing association)	March 2016
Son	Searched “Wirral Telecare” on google looking for subsidized/free council service (nothing available)	March 2016
Son	Looked for pendant alarm that resembled jewelry that had been seen at an AAL exhibition	March 2016
Son	Looked up “Age UK” and phoned them	March 2016
Son	Appointment made with a representative to visit mum	April 2016
Age UK sales representative, Mum & Daughter	Representative visited house and demonstrated the system	April 2016
Mum	Not sure due to call center in Devon, key holder identification, did not like salesperson, monthly charge	April 2016
Son	Searched council website again – no real section on telecare, even though the service is provided	
Son	E-mailed “Magenta”, other local provider, no response	May 2016
Son	Searched telecare on google following a link from Tunstall website	May 2016

(*continued*)

Table 2. (*continued*)

Actors	Process - steps	Time
Son	Reviewed packages from Telecare24	May 2016
Son	Reviewed packages from Boots – more expensive than Telecare24, not sure about falls monitoring, no picture of pendant	May 2016
Son	Checked forums on financial website. Nothing for telecare but personal alarms showed some results. Most of the equipment/services were low cost and required some local set up so required some skilled ICT knowledge. The forums focused on traditional tech like large button phones rather than pendant alarms. It was felt that this would put off people who were looking for a standard solution as it seemed to be relatively technical people trying to do something as cheaply as possible, rather than looking at the reliability and responsiveness of the system. www.moneysavingtexpert.co.uk	Jun-16
Son	Checked DLF website and considered visit to look at systems in local branch http://www.dlf.org.uk/content/about-us http://www.livingmadeeasy.org.uk/contacts_edc.php	Jun-16
Son	Looked at comparison website with lots of suppliers found on google - narrowed down to Merseyside but showed mainly National providers that covered the area. http://www.housingcare.org/service/list/s-24-telecare/l-451-merseyside.aspx	Jun-16
Son	Checked Local Authority website. No mention of telecare being available. Son rang the Adult Social Care line and they processed the referral then made an appointment. www.wirral.gov.uk	Jun-16
Local Authority	Visit to mum to explain options and process	Jun-16
Daughter	Explanation of key safe, impact on local neighbors	Jun-16
Local Authority	Key safe installed by Local Authority	Jul-16
Local Authority	Pendant alarm System installed	Aug-16

Lesson learned from the use case generation, amongst others, are that the purchasing process of an AAL product takes too long and was resolved only via a telephone enquiry, as there was no information on the local authority website. Furthermore, the son needed to search in various websites to compare the different AAL products characteristics and did not always found the needed information. There is a lot of information available from commercial providers, but the public-sector provider has no web-based information so far. Besides the 82-year-old woman, many actors are involved in this process, namely her daughter, son, an occupational therapist, the Council Website and an Age UK sales representative. In this use case, it is the non-technical issues, rather than the technical choice, which causes problems for the involved parties. The ActiveAdvice applications are designed with the exact intention to ease this process and make it less time consuming for all actors involved.

3.2 Better Understand ActiveAdvice Stakeholders: User-Centered Requirements Analysis

The first phase of the analysis helped to identify the stakeholders of AAL products and services in general, as well as to gain a better understanding of the ActiveAdvice stakeholders. After that clarification, the next step encompassed a user-centered requirements analysis [58]. This methodology involves users from the onset of the solutions' development, to give an early feedback to developers and researchers regarding user requirements, preferences, acceptances and expectations – in this case the use of an online advisory and feedback platform on AAL products and services.

Semi-Structured Interviews. Overall, 38 semi-structured interviews were conducted. The aim was to identify and clarify the highest possible number of issues, which are supporting or preventing the development, and in the ongoing process, the implementation of the ActiveAdvice platform. This qualitative technique was chosen because it allows an in-depth analysis and learning of what people expect and how individual circumstances determine their reasoning. It is important to note, that the results can neither be generalized nor quantified. Nevertheless, they give insights in the stakeholders' different perspectives and needs.

Potential participants corresponding to the nine previously defined segments were approached through convenience sampling strategy. The 38 interviews included in the analysis were rather evenly distributed among the different stakeholder groups: older adults and relatives (n = 12), business representatives (n = 14), and members of local and regional governments or representatives of end user organizations (n = 12). The data was collected in each ActiveAdvice partner country, distributed in the following way: Austria (n = 5); Belgium (n = 3); the Netherlands (n = 10); Portugal (n = 7); Switzerland (n = 6); and the UK (n = 7). The interview guidelines were built in a collaborative effort among all partners. Three different guidelines – one for each stakeholder group – were developed. With respect to older adults, the general use of the internet, motivations to use social media, attitudes towards feedback giving and advice as well as the general awareness of AAL solutions were in focus. Businesses were asked to comment on their use of the internet to promote their product, to get in contact with their customers. They were also asked to reflect on feedback features, their marketing and how to integrate their products and services into an AAL platform. The government stakeholder group was asked to comment on AAL developments, products and services in a more general way. Of interest was e.g. whether they were aware of AAL solutions, how they make themselves familiar with developments, whether they promote AAL products, and in which role they could contribute to an ActiveAdvice ecosystem.

All interview guidelines were first available in English and then translated into the respective languages (Dutch, German, French, and Portuguese). Adaptations to local and national specifications were also performed. This was necessary to grasp the differences in e.g. the role of health insurances, the social security systems and, legal and financial issues. All participants received the study information sheet and gave their informed consent. Depending on the interviewees' availability and preferences, the interview was carried out face to face, in a teleconference or by telephone. Each of the interviews took between 30 to 45 min.

Matrix Analysis. The data was analyzed using the matrix analysis method. This method was chosen because it provides a structure with which large amounts of qualitative data can be categorized and analyzed, allowing to obtain new insights across topics that have previously not been established [59, 60]. For every stakeholder group (consumers, business and government), a separate matrix table was created. All answers were then transferred into the matrixes and all answers were anonymized. Each column represented one interviewee (i.e. end user 1, end user 2, etc.). Likewise, each row covered one individual code, which has been defined based on the overall aims discussed above (i.e. social media, giving feedback, trust in online reviews, etc.). Consequently, the analysis offered a better understanding of the individual assumptions, as well as a comparison across the cases of the different interviewees' assumptions.

4 Results: Stakeholder Perspectives Under Focus

For the ActiveAdvice project, it was important to gain an understanding across the participating countries and stakeholder groups about the state of the art with respect to advice, feedback, and availability of AAL solutions; and, furthermore, what the stakeholder groups expect from an online advice and information platform. Below, the most important results from the user-centered requirements analysis are presented. These findings support a better understanding of different and common stakeholders' motivations, intentions, needs and expectations in the scope of the ActiveAdvice project. The results section is organized along the line of two main insights. The three stakeholder perspectives (Cs = consumers, i.e. older adults/relatives, BR = business representatives, GR = government representatives) are presented in an integrated manner to highlight differences and similarities in their perspectives towards each topic as well as to develop a holistic picture.

4.1 Attitudes Towards ICT and Internet Use

ICT Skills, Interest and Internet Use. In general, Cs have demonstrated interest in ICT-based solutions. However, not all interviewees in this group reported to use the internet regularly, let alone to consult the web for health-related information. This constraint was also identified by GRs, who have shown concerns about whether or not older adults would be able to access an advisory platform in the first place. Perceived barriers for access include older adults' lack of technology or ICT skills (technology illiteracy) or fear of technology/learning process and missing access to technological devices or internet connection. GRs also stressed that different profiles for older adults must be taken into account, since those in need for geriatric help are very unlikely to use the internet.

For those older adults who use the internet, particularly to gather health information, a preference for receiving information (e.g. via newsletters) rather than actively searching for it was expressed. Care consultancy is more often sought to be found in the virtual reality; but the use of internet is often reduced to a first consultancy rather than an ongoing advice. Regarding social media as a means to look and provide information, neither Cs nor BRs see it as a preferential or priority channel. On the one hand, Cs tend to see social networks as a means for social interaction rather than a platform for learning or being informed about products and services. On the other hand, BRs tend to report a lack of resources or skills to invest in the use of social networks, although they wish to do it at a later stage. When it comes to customer interaction, they prefer face to face (f2f) interaction, as it provides better means of communication when building up a relationship with the customer. Furthermore, Cs reported to only rarely have used online catalogues (not necessarily of AAL solutions) so far. On this topic, BRs consider that ActiveAdvice must avoid becoming just another online catalogue providing a selling service.

The main observations by Cs and GRs on these topics are in line with the literature reviewed. Some reasons for the low acceptance of technology by older adults are: poor ICT skills, fear of both the technology itself and the learning process, lack of financial resources to purchase and maintain devices and internet access [8, 29, 34, 61, 62]. It is documented, however, that barriers associated with ICT skills for older adults will tend to decrease in future generations [36]. In this study, some Cs report not to have searched for health information online at all. In contradiction, searching for health information was reported in the literature as one of the activities most performed online by older adults [29].

Knowledge of AAL Products and Services. The three groups of stakeholders interviewed tend to consider that ICT products and services are not well known by older adults, and they welcomed the possibility to raise awareness and give information. GRs stressed that either older adults do not know where to find solutions or they only start looking once they are in need. Hence, GRs considered that the ActiveAdvice project should target the awareness raising as much as offering advice. In the BRs perspective, more and better information on AAL solutions is welcomed in order to make those solutions widely known. Evidence from literature reviewed pointed to the same direction when concluding the lack of general public awareness about AAL technologies. For example, caregivers had perceived a lack of relevant information available on AAL technologies and its benefits or its availability, only when a point of crises was reached; while business stakeholders identified it as an obstacle to introduce and succeed with these products and services in the marketplace [12, 36, 61, 63].

Online Promotion of AAL Services and Products. BRs report to use internet predominantly for marketing. However, some also stressed they do not use it at all, one of the reasons being the fact that while online promotion reduces costs from a customer perspective, this is not automatically the case for businesses. The internet was seen as an important means for promoting more simple solutions: the less maintenance a product needs, the more suitable it is to be promoted online. In BRs perspective, the internet loses importance with business to business (B2B) promotions, since negotiations are dependent on time, experience and trust building. Similarly, GRs also seem to use multiple formats for AAL products and services promotion, including ICT-based promotion, but also other strategies (e.g. events). GRs stress that regardless of the channel used, promotion should include a focus on services rather than on technologies, in order to guarantee solutions' quality and flexibility, i.e. allowing easy entry for companies to promote services and products. In either case, ActiveAdvice is seen as an opportunity by GRs to raise the level of awareness of AAL and having a broadened overview of the entire European AAL market.

Face-to-Face (f2f) Contact. Both Cs and BRs have shown a preference for f2f contact with each other. For consumers, both buying or getting advice online still compete with the f2f experience, which is perceived as more trustworthy. For BRs, the f2f approach allows customers to get to know and build a relationship with the company. Moreover, complex AAL solutions need to be tailor-made and adapted, tested and introduced to the specific application-settings, and therefore buying online without guaranteeing support and service is perceived as too risky. GRs also stress that technological innovations, social interaction and prevention of loneliness and struggling are important issues to consider. Similarly, literature reviewed produced on the usability evaluations has shown that solution's uptake can be hindered by older adults' fear of losing social interaction, f2f contact and becoming lonely [26, 33, 64, 65]. However, it has been reported that if technologies are seen as facilitators of new social interactions rather than a replacement of human interactions, this apprehensiveness can be partially minimized [61].

Consumer-Business Online Interaction. BRs have shown to be more receptive to online interaction than Cs. While the former considered online interaction with potential customers as very important, the latter might experience businesses directly communicating with them (e.g. via social networks) as an intrusion into their privacy. The emergence of the privacy topic in this data collection is not surprising, since older adults' concerns about security and privacy in ICT use – particularly when health and well-being data is involved, or when it comes to online transactions – has been extensively mentioned in the literature [10, 16, 26, 33, 66, 67]. In spite of BRs' more favorable positions regarding online interaction, these actors also mentioned some deterrents. In particular, it was stressed that everyday activities are dominated by a f2f and problem focused approach: BRs appreciate to get in contact with their customers as quickly as possible, but they understand it as an action-and-reaction communication pattern. Moreover, they stress that communication must not take place in a "public sphere", a statement also extended to feedback and advice.

4.2 Feedback and Advice in an Online Environment

Trustworthiness and Usefulness of Online Feedback. Most important for Cs is feedback about AAL-solutions, preferably by other end users. Cs tend to value feedbacks offering a description of the product or service (e.g. price, functionalities) and the related personal experiences; information on the service providers; information on the website or platform presenting the solutions; and information on the feedback giving person. Cs declare to value family members' and friends' comments for evaluating whether or not a product or a service is reliable, useful or trustworthy. However, even with feedbacks from reliable customers or experts, trust is still the biggest concern for them when accessing the web – thus, the f2f experience is preferred. In the position of giving feedback themselves, Cs report to be driven by negative incentives such as complaints about unfulfilled expectations. For BRs, these negative incentives are a reason to be hesitant about feedback in a "public sphere". When customers interact, and discuss their positive and negative experiences, companies of course run the risk that too much negative feedback starts to affect the promotion of a product. However, they also have the chance to learn first-hand about how their product or service is perceived and accepted in the market [68]. Nevertheless, for BRs, whereas real user testimonials (on the own website or on a meta-site) are welcomed, they doubt, in general, the need for and usefulness of online customer feedback. Moreover, businesses typically do not appear on websites where customers can place their reviews. Furthermore, Cs' willingness to provide feedback can be dependent on the age-generation. Literature in that respect clearly differentiates between Millennials and Baby Boomers, with the latter preferring to give feedback in a f2f context rather than in the virtual reality, especially as the privacy cue has priority for them [69]. Yet, in general, interviewed Cs expressed interest in becoming more active and successful users as well as commenters in a secured, easy-to-use environment.

Neutrality as Precondition for Advice. In general, both Cs and BRs considered advice as an important and needed service. Cs demonstrated their willingness to learn about the best products and/or services for them. However, if asking for advice is something that Cs would like to do, they currently do not seem to be doing it. Lack of trust in online-advice is one of the reasons invoked for that. Hence, both GRs and BRs stress that quality of data and neutrality are important features for them to get involved, and for consumers to trust in online advice.

Both GRs and BRs highlighted that when providing advice, it is important to understand what the customer really wants and based on such understanding, offer them a customized, specific support, and one-to-one advice resulting in a perceived benefit. Regarding the question of who should provide advice, BRs consider that, on the one hand, advice is best given by those who sell a product, but on the other hand, becoming advisors themselves was not seen as an option, due to a lack of resources and the disruption of the neutrality condition. Therefore, a "neutral" body or a virtual agent is suggested to perform this task. GRs suggest that a panel of older adults could test products and the platform itself, and similarly, volunteers could act as advisors on the platform.

With regard to digital and virtual advice, it was argued that the use of virtual agents, particularly in the e-commerce context, is especially relevant to older adults due to the anticipated decline of physical and cognitive abilities [70]. Studies have supported the strong impact of virtual agents in the context of online shopping, arguing for their relevance to address age-related navigational needs [71]. However, building trust is a challenging task. For example, consumer cohorts have different trust understandings and thereby reference systems. Furthermore, peer-endorsement seems to have a different impact on consumer behavior, depending on the national context. Clearly, trust is dependent on website-interface variables; while provider's brand strength, online expertise or web site familiarity were less influential. The presence of provider advice, privacy cues and community features are crucial [72, 73].

AAL Solutions, Platform Features and Usability. When questioned about the AAL services and products most relevant for end users, GRs stressed that platforms must include products that take the older adults' needs and their physical and cognitive ageing process into account. Both Cs and GRs referred that besides offering information on

AAL products and services and their suppliers, the ActiveAdvice platform should contain information about social services, care organizations and other informative websites (e.g. for dementia, epilepsy). Moreover, Cs expected the inclusion of so-called “flow charts” on the platform, as a tool to help older adults solving problems or improving situations step by step, as well as guidelines for ordering products online.

When reflecting on the features that a platform like ActiveAdvice should have, both Cs and GRs stressed the importance of inclusive design. In addition, a clear communication strategy, a simple, and a well-structured web-layout can help to build trust. Mistaken wording can lead to negative emotional reactions, causing the end user to abandon the technology [37]. It was suggested by GRs that one possibility to address the problem of accessing online information is to design the website in a way that allows neatly formatted and easily readable printouts. Cs stressed the importance of platform features influencing its use, such as the website organization, used colors, the amount of information included, and, as a critical factor, security and safety. The security topic was highly valued by BRs, as was the neutrality, i.e. the platform needs to guarantee impartiality in the presentation of products and services. Neutrality was also highly esteemed by GRs, who suggested that the quality standards should be transparent, such as the criteria and guidelines on how products and services are being evaluated.

BRs have suggested that specific functionalities of ActiveAdvice must include videos (with comments by developers and users) and “qualitative photographs”. Both should help to best describe the solution as well as its functionality; and include e-Expert stories. Moreover, testimonials for the platform itself and not only for the single services can be a way to assess and improve platform reliability. BRs also mentioned that both the products and the platform need to be certified, as this is a guarantee for quality management; and thus, a valuable and reliable offer – for both businesses and the customers. No particular information on a possible certification process and institutions were provided. Additional features such as the inclusion of a telephone number by country and the presentation of the platform administration were considered by GRs as relevant factors for raising the website’s credibility.

ActiveAdvice Perceived Added Value. All stakeholder groups appear to anticipate and recognize positive effects of a pan-European advisory platform. GRs value the potential benefit of the ActiveAdvice platform for experience exchange between organizations in stimulating older adults to use ICT solutions, in offering their own product(s) or specific assistance on a local municipal/communal level. Offering information on the AAL market, such as data on suppliers and services and feedback from end users that could feed into the evaluation process for procurement is essential. In addition, it could possibly serve as basis for policies for care for older adults. Moreover, ICT support was considered helpful for businesses promoting AAL solutions, with interoperability with other systems being seen as an opportunity. A platform such as ActiveAdvice was also seen as providing an opportunity for smaller suppliers to promote their products.

Nevertheless, some BRs have raised concerns and shown reluctance in contributing to a future platform due to a potential risk of competition. Also, for the occurrence of the benefits pointed out above, both GRs and BRs stressed that ActiveAdvice must guarantee the quality of products and services, as well as their security, and, as previously mentioned, neutrality. Those are the baseline conditions for these stakeholder groups to allow their products and services being promoted through the platform, and to promote the platform themselves. BRs also asked for transparency with respect to the business model and the responsibilities of each stakeholder involved and expressed that they need to make sure that the platform is accepted and reliable. GRs suggested that a credible quality label would ensure reliability and trust as well as mobilizing a wider support from governments, large associations with high reputation, suppliers and local persons providing services (e.g. general practitioners). The involvement of municipalities and local authorities was considered by GRs as essential to better promote the platform and to increase trust amongst older adults.

5 Discussion and Lessons Learned for the ActiveAdvice Platform

When it comes to functional requirements, the ActiveAdvice platform builds on the results from the user requirements analysis. The three stakeholder groups may share requirements for basic functionalities, such as a desire to gather comprehensive information and a holistic market overview being offered. However, there are also stakeholder group-specific functional requirements that are not necessarily shared among all of them.

Both consumers and governments share a need for comprehensive information and decision support. Thus, the system has to provide (i) digital advice and decision support as the core of the ActiveAdvice platform; and (ii) guidelines, use cases and use stories in order to illustrate AAL products and services. In addition, based on the identified needs for community exchange and feedback for the consumer stakeholder group, a feedback function for review and rating should enable them to generate content and exchange experiences about AAL services and solutions. This latter function is a clear contrast to commercial expectations. The ActiveAdvice platform developers need to manage these different expectations accordingly. Then again, businesses do want the possibility to get in contact with their customers, hence a functionality for customer contact and customer interaction is required. With the use of profiles for vendors, products and services, businesses can provide information on the products and services they offer.

In order to provide governments with the needed information, an additional functionality providing accessibility guides and awareness sheets will be implemented to allow showcase retrieval for best practice. Furthermore, knowledge channels are planned. Through them, the ActiveAdvice platform also contributes to the awareness raising of AAL products and services. It is both an information feature as well as an AAL development sensitizer. The “ActiveAdvice Information and Awareness Hub” was conceived and recently launched precisely with the aim to answering these requirements. In line with this is the functional requirement for promotion and networking. Such a functionality allows businesses to provide up-to-date information about their respective services and products, thus ensuring the timeliness of the provided information - this, then, will benefit both the consumer and government stakeholder groups.

Based on the user requirements analysis, the ActiveAdvice platform will provide three main functions:

(i) providing up-to-date information on AAL products and solutions;
(ii) offering feedback, advice and decision support; and
(iii) giving businesses the opportunity to present their products and services.

With these functions, the ActiveAdvice platform presents itself as an integrated communication tool with the potential of bridging the gaps between AAL stakeholders. It facilitates cooperation, information exchange and, ultimately, e-commerce. More than its value regarding the front-end (i.e. the website/app), the power of the ActiveAdvice platform lies in connecting the organizational, non-visible parts, in the back-end.

6 Conclusion

The AAL field would profit from more collaboration and coordination among stakeholders. This call for multi-stakeholder partnerships comes not only from academics but also from other protagonists in the AAL fields, such as the industry and CSOs as well as governments, and the European Commission (EC) [34, 67]. The integration of different stakeholders' perspectives in the development and implementation of AAL solutions is a necessity as well as a challenge. This holds also true for the development of the ActiveAdvice platform. In that respect, the literature analysis confirms that the development of a platform that supports both the sharing of information and building up of networks between different stakeholders, is a comprehensive task. Moreover, this paper demonstrates that interests and intentions vary between stakeholders. While for example the need for more information on AAL developments is expressed by all three stakeholder groups, at the same time reservations from the business side towards the extent and format of product information is articulated. The same applies to AAL advice. Businesses would want to provide advice; however, they consider it as a service to be offered one-to-one rather than online. In addition, governments would need an AAL product and service information tool, however, they are not sure whether to at all, and how they should contribute.

The ActiveAdvice project has applied a multi-stakeholder perspective right from the project start, by that, facing the many different contradictions concerning the stakeholders' interests, needs, knowledge and motivations. It has the potential to integrate and facilitate an AAL product and service environment for all stakeholder groups. However, it has to prove to all stakeholders that it is safe to interact and share experiences within the ActiveAdvice platform, that it presents a neutral and reliable environment in which stakeholders can trust. While ActiveAdvice is designed to be pan-European, it is clear that ageing will always happen locally.

The ActiveAdvice project also needs other developments to take into consideration: we observe a shift happening in the influence of physical and virtual realities. Authors detect the introduction of a new regime, namely the establishment of engagement ecosystems. These integrate both the virtual and the physical environments with the purpose of optimizing the promotion and selling of products and services. The purely virtual service landscape in such an engagement ecosystem, is enhanced by real world physical environments. Prominent examples are e.g. Google or Microsoft and Apple [74]. The ActiveAdvice EU-funded project will need to take into account this trend to shift from a purely online interaction to an integrated logic.

In the ongoing ActiveAdvice project, the stakeholder ecosystem is focused even more. In a next step, the respective stakeholder requirements will be integrated into the user testing phase. The overall aim again is to ensure the possibility of (knowledge) exchange and collaboration within the ActiveAdvice platform and to build up an engagement ecosystem. Moreover, especially the concept of "active advisors" [75] offers the possibility to bring together various stakeholders with the use of the ActiveAdvice platform.

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Delivering Information of General Interest Through Interactive Television: A Taxonomy of Assistance Services for the Portuguese Elderly

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Abstract. In the context of an ageing population, providing relevant information to support seniors' daily activities plays an important role to promote these citizens' quality of life. This study is part of the +TV4E project, which aims to develop an Interactive Television (iTV) platform to transmit personalized information regarding Services of General Interest (SGI) to senior citizens. In order to better assess seniors' preferences and expectations this study aims to propose the Assistance Services of General Interest for Elderly (ASGIE) concept and taxonomy. To achieve this, we set out to collect contributions from specialists in welfare promotion and public policies development for the Portuguese elderly to elicit detailed perceptions on the information needs of these population segment. The validity and relevance of contributions gathered along with these specialists were subsequently confirmed in a survey with 23 seniors recruited in the context of the +TV4E project. The ASGIE taxonomy is composed by 7 domains of information: Healthcare and Welfare services, Social services, Financial services, Culture services, Security services, Transport services and Local authority services. Findings from this study are relevant for authorities in charge of designing, implementing and monitoring public policies for seniors, as they present valuable indicators of information needs of these citizens.

Keywords: Information needs · Taxonomy · Public policies
Social services · Seniors · +TV4E · Portugal

1 Introduction

Ageing is one of the most important social challenges of the 21st century. Though increased longevity is something to be celebrated, for a considerable part of the population ageing may be distressing and problematic if there are no conditions for being independent, active, and healthy for as long as possible.

In many countries people live significantly longer than they did a few decades ago. The number of senior citizens in 2000 came from 600 million to nearly one billion in 2015 and this number is projected to reach 2.1 billion by 2050 and 3.1 billion by 2100

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[1, 2]. Particularly, between years of 2015 and 2030 population aged over 60 years in European countries will increase by 23%, while in less developed regions such as South America and Africa this population segment is projected to grow around 50% or even 70% [1]. These changes have resulted in an expressive reversal of the age pyramid and caused great economic impacts on public health and pension systems. So far, the leading response for the social and economic implications concerning older people is the development of active ageing initiatives to enhance participation, health and security, as well as to achieve quality of life as people age [3].

In what concerns Portugal, between the years of 2001 and 2011 the senior population increased from 16% to 19%, leading the population ageing index from 102 to 128, which means that for each 100 young people there were 128 elderly people [4]. According to PORDATA Institute report [5], in 2015 the number of Portuguese inhabitants aged 60 or more finally surpassed the number of children, adolescents and young adults (less than or equal to 24 years), which puts Portugal as one of the most advanced countries in the society ageing process in Europe. Moreover, even the most optimistic projections (considering high levels of fertility and lower levels of mortality and migration) indicate that in 2060 the number of seniors in Portugal will be around 2.7 million, leading the population ageing index to 287 [4]. In 2080, it is expected that for each 100 young people there will be 317 elderly people [6].

The European Commission (EC) recognizes the ageing population theme as a common challenge to all European countries. To address this challenge it was established an European Innovation Partnership (EIP) on Active and Healthy Ageing (AHA), which focuses on actions developed in 3 work fronts: prevention, screening and early diagnosis; care and cure; and active ageing and independent living [7]. Also, the EC has launched several programs, flagship initiatives and action plans to foster structural measures to create and improve public and social services. Some of these measures are e-government solutions, creating new sources of growth and social cohesion according to a quality framework and promoting the deployment and usage of modern accessible online services [8]. These measures were envisioned by the EC as an opportunity to all European countries to lead the world in active ageing projects, by creating innovative technologies that enable older people to live independently and more active in society [9]. These technologies play a vital role by enabling individuals with the access and the ability to obtain information and knowledge about several areas of their daily living situations [10]. Portuguese government has been also strongly investing on this way to provide public and social services. According to comparative studies based on the digital public administration of European Member States and published by the National Interoperability Framework Observatory [11], Portugal stands out in three important metrics concerning public electronic services implementation: (i) user centric (to what extent information is provided to users and perceived by them); (ii) key enablers (to what extent technical pre-conditions regarding information security are present) and (iii) transparency (to what extent the government is transparent on its own responsibilities and performance, on public services delivery and on personal data involved).

Strategies and measures implemented in recent decades put Portugal at the forefront of Member States in terms of provision of public electronic services, with performance levels above the average of European countries in the field of national electronic government [11]. However, despite being among the top three in Europe concerning quality and availability of public electronic services, Portugal still faces low levels of adoption of these new digital interfaces due to a set of structural factors, such as "low levels of computer skills of the population" [12]. Moreover, much of the population still not reached by these new sources of information regarding public services, as usually they require direct searches in the media, previous registrations, among others.

The reach of information about public and social services is even lower when considering the elderly as the target audience. In Portugal, given the current scenario of info-exclusion [13] and low literacy levels [14] of seniors, they are commonly in a disadvantaged position for not being aware of the welfare benefits available to them, though they are the ones who most need assistance and information [15]. Such exclusion contributed to the fallacious perception of older people as being passive individuals, family-oriented only and disinterested in social and political participation [16].

According to Everingham et al. [17] providing information needed by older people is critical to "age well and socially included". In this way, effective delivery of public services information considering elderly needs is vital for a successful development of public policies. Furthermore, fulfilling information requirements of elderly using personalized and acceptable methods may give them more independency and autonomy.

In this context, the +TV4E project comes up as a platform for interactive television (iTV) to enrich the television experience with the integration of informative contents about public and social services in a personalized way [18, 19]. The target audience of this project is the Portuguese elderly population considering their characteristics, specific needs and expectations in the use of public and social services. This project aims to leverage the proximity and familiarity that elderlies have with the television (TV) to develop an iTV platform in a promising way to access information that otherwise would not be easily accessible. The +TV4E project is an on-going research action project, and to achieve this goal, it provides mechanisms for gathering and transmitting informative contents regarding public and social services, which in turn, must be properly classified to meet the user requirements and interests. In addition, this classification of services is discussed in this paper and will be used as input for the +TV4E content recommender system [20, 21], which is responsible for selecting and matching the informative contents with the users in a personalized way.

The research presented in this article sought to find out a list of public and social services available for seniors in Portugal and, according to this list, the concept and taxonomy of *Assistance Services of General Interest to the Elderly* (ASGIE) is proposed. Such taxonomy categorizes not only services, activities, resources, and social programs directed to the elderly, but also the ones that might assist them in their daily activities.

This paper is structured as follows. The theoretical framework section reviews some concepts regarding public and social services in Europe as well as some literature works on information needs of elderly that supported a preliminary version of the taxonomy. Section 3 describes the methodology applied by this study and in Sect. 4 a proposal of taxonomy of Services of General Interest tailored for the Portuguese elderly population is presented. Finally, in Sects. 5 and 6, discussions and final remarks are given singly, especially with respect to the context of +TV4E project.

2 Theoretical Framework

Over time, a set of transformations occurred concerning the terminology of "public services". Following it is presented a historical view evolution of the concept of Services of General Interest (SGI), as well as the information needs of elderly people, in Portugal.

2.1 Services of General Interest

In the late 1990s there was a change in the terminology used in the EC to designate public and social services due to discomfort and misunderstandings around the multiple possible meanings and interpretations of the many-faceted "public" word, which can refer to the group of beneficiaries of the services or to the public institutions providing it. Though there is no precise definition given by the EU [22], the term SGI has emerged as the main designation in Europe to comprehend the services tailored to fulfil the citizen's wellbeing, considered to be of general interest by the public authorities and thus subjected to a set of predetermined public-service regulations [8, 23]. The SGI comprehend a wide range of activities, functions and resources, from telecommunication networks, postal services and water supply to healthcare, education and financial services [24]. These services are vital for the daily life of citizens and enterprises, essential for ensuring the sustainable development of the European Union (EU) in terms of higher levels of employment, social inclusion, economic growth and environmental quality [8]. Also, these services are important to promote social, economic and territorial cohesion throughout the EU.

Some other terms related to the SGI are also applied and considered by a set of EC communications, reports and papers. The concept of *Services of General Economic Interest (SGEI)*, sometimes used interchangeably with the term SGI, covers services of an economic nature which Member States or the Union have elected to subject to a series of public-service obligations by virtue of a general-interest agreement [23]. It includes economic activities that public authorities recognize as being critical to citizens and that would not be supplied (or would be supplied under distinct conditions) if there were no public regulation.

The concept of *Social Services of General Interest (SSGI)* refers to a subset of SGI which plays a crucial role to improve quality of life and provide social protection of citizens, in order to enable economic and territorial cohesion, high employment, social inclusion, environmental quality and economic growth [25]. These services are person-oriented, designed to respond to vital human needs, particularly to support the ones who are in vulnerable position, and are addressed to the whole population, independently of wealth, income or any other idiosyncrasy.

Finally, the term *Universal Service Obligation (USO)* consists of predetermined rules and requirements stated to make sure the SGI will be available to all citizens according to certain parameters of affordability, quality and accessibility [8]. Setting up specific USO at a European level is essential for the market liberalization of service sectors, such as transports, postal services and telecommunications.

Other SGI related definitions and concepts may be found in scientific literature and in project research reports. Tagarev et al. [26] elaborate on the concept of *European*

Essential Services (EES) as functions that "allow to preserve the functioning of government, economy and citizens under extreme conditions". In the context of the SeGI ESPON project [27], the concept of SGI is divided in SSGI and SGEI only. Hence, SSGI are composed by labour market services, education, healthcare, childcare, social care, housing and social assistance services; while SGEI comprehend services of gas, electricity, postal services, transport, Information and Communications Technology (ICT) and electronic communications as well as water and waste management [27].

Debates on the "lack of clarity on terminology" and on the fact that "concepts are used interchangeably and inaccurately" still draw attention [8]. In their research work, Bjørnsen et al. [24] discuss to what extent SGI can be meaningfully determined and interpreted based on scientifically procedures, as the definition of SGI itself implies no clear guidelines about what specific types of activities, processes and resources are involved. Nevertheless, according to the authors some exemplifications typically involve "areas into which the economic and/or government activities of a country are divided" and industries. These areas refer to the main institutional sectors (public and private), as well as to policies involving actors, activities and resources of these sectors. Some examples of SGI could be implied based on the *Green Paper on Services of General Interest* division of SGI in "non-market as well as market services which the public authorities class as being of general interest and subject to specific public service obligations" [23]. Thus, market services would comprehend activities delegated to mostly private entities (e.g. water and natural gas supply, transports, electricity and telecommunications), whilst non-market would designate services delegated typically (or fully) to public entities (e.g. justice, social security, financial services, housing and health care) [23].

This concept of SGI was intentionally built to replace well-established concepts, such as "public services", to promote a common language in the EU and respect local heterogeneities. So, all definitions made by the EU regarding SGI do not reflect any national terminologies on what should be provided or regulated as a service. For service obligations typically vary among the Member States and local historical, economic, cultural and political developments can lead to different understandings, agreements and definitions. Therefore, despite the several normative statements concerning the delivery of SGI specified at the European level, the development of policies and, in many instances, the provision of the services themselves remains mostly a responsibility of each Member State. So, the development of public policies regarding SGI as well as the activities, resources and functions entrusted to public authorities' regulation are decided in a local perspective, considering particularities and requirements of the citizens who benefit from them.

The development of SGI to address citizen needs have been receiving growing attention of EC and EU Member States, which considers these activities, resources and functions as essential components of the modern European society's model, as they are of great importance to foster high competitiveness of the European economy as well as to enable social and territorial unity among Member States. This premise is stated by the *White Paper on Services of General Interest* [28], which emphasizes the importance of the SGI as one of the main pillars of the modern European society model. Thus, it is necessary to "ensure the harmonious combination of market mechanisms and public service missions" to achieve the EC objectives in terms of European cohesion and convergence policies. Therefore, the development of SGI according to certain parameters of availability and accessibility as well as according to a proper territorial distribution represents a key strategy for the EU. These developments intend to ensure that all citizens and enterprises will be provided with affordable and high-quality services.

Given the importance of the SGI to maintain and enhance older citizens' quality of life it is also important to consider this specific population information needs when developing new services and improving the existing ones.

2.2 Information Needs of Elderly

Though there has been an increasing interest among researchers in investigating the information needs of elderly [29], research studies on this subject are still scarce in scientific literature [30]. Considering elderly information needs is fundamental for effective planning and implementation of services and public policies to assist this population segment.

Zou and Zhou [30] conducted a survey with 600 respondents in a rural community of China in order to list the sources and types of information on which elderly often rely. Based on the survey results, a typology of five categories of information needs was established: physiological (food, clothing, care and shelter); safe (healthcare and pension policy); affective (friends and family activities and club activities), Respected (self-assessment and social evaluation) and self-realized (jobs and knowledge skills). Also, the results showed that information accessibility, reliability, and relevance highly influence elderly choice of information sources. With respect to information sources, audio-visual media were preferred (e.g. TV and radio).

Similarly, audio-visual media were the most preferred source of information for elderly according to a research based in Nigeria [29]. This study sought to identify Nigerian elderly needs of information as well as the sources they are familiar with. Findings revealed that elderlies are mainly interested in information about health conditions, pension/finance, government policies, current affairs, and transport. Also, the authors pointed out some factors influencing the information seeking behaviour of older people, such as problems with access and availability.

Information must be relevant, accessible and appropriate to older adults' expectations to be effectively delivered and consumed. This is aligned with a study by Barret [15], which investigated and analysed the information needs of older people in the United Kingdom in a nationwide survey with 1630 respondents. Questions regarding the most common day-to-day problems, areas and sources of information older people were aware of, and preferred means of getting such information helped to evaluate issues on finding information about formal support. Results showed that respondents demand for information about financial and practical help, housing, products and home adaptations, support and services at home that are available to them.

Some authors consider that elderly often find it very hard to point out subjects and information they are really interested, as usually they only require such information at a time of crisis or life change. So, instead of investigating about topics of interest, Everingham et al. [17] preferred inquiring about people recent information needs. The authors conducted a study to "understand issues impacting on older people's capacity to access relevant information" as a part of a larger project which developed a model of local collaboration in eastern Australia. Conclusions show that older people seek information about availability of programs for delivering hot meals, home health care, special transportation, and other assistance services. Also, they wish to know all the benefits, concessions, rebates and subsidies they are entitled to.

There are two paths available to receive information: information may be deliberately sought and retrieved or may be opportunistically received by chance and, thus, be discovered and noticed. In this way, assuming that information discovered and noticed reflect people's everyday life problems, concerns and lifestyle, Pálsdóttir [31] proposed an exploratory study about opportunistic information discovery by elderly people in Iceland. According to the author, it is consensual for elderly that authorities should disseminate in a more efficient way information regarding formal support from the state or the municipality (e.g. house cleaning, driving service, home delivery of meals, assistance with bathing, administering medications, etc.), available healthcare programs, and financial support or reimbursements that older people are entitled to.

The aforementioned studies on seniors' information needs show that information about healthcare, financial help, pensions and local policies are recurring demands among senior citizens from many countries. To cope the lack of studies concerning the information needs of the Portuguese elderly, previous works of our research team consisted in assessing the SGI on which the older adults of this country would like to receive information about [10]. These works served as basis for a draft of the services belonging to the taxonomy proposed by this research. The development of a proper taxonomy of SGI considering senior citizens information needs presents a valuable artefact for government entities so that they can effectively propose and implement more adequate policies for a promotion of the quality of life. Details on the process of composing this taxonomy follows.

3 Methodology

This study forms an early stage of +TV4E project, a two-year action research project conducted at University of Aveiro, Portugal, which proposes an iTV platform for delivering personalized informative contents about SGI to senior citizens. Thus, in order to achieve a more adequate and personalized approach for the content delivery it is necessary to create a proper categorization of such information [21].

In order to consider particularities of Portugal as well as to establish the validity of the current study, our research team decided to invest in a preliminary exploratory approach to gather information about: (a) development and implementation of SGI in Europe; (b) common information needs of elderly and (c) respective sources of information. This approach consisted of a literature survey of research in international databases with the keywords "elderly" and "information needs". As result, it was produced a list of services in which elderly would be interested in receiving information.

This list was composed by three categories of services: (a) Healthcare services; (b) Social and financial services, and (c) Local (nearby) services. Though rather incomplete, it already had most of services available to Portuguese seniors, and served as basis for guidelines and questionnaires used in subsequent phases, which consisted of:

- A semi-structured interview with an expert in public health promotion for Portuguese seniors;
- A focus groups carried out with experts in public policies development in Portugal;
- Surveys with seniors.

Figure 1 shows in a schematic form the methodological process that allowed the creation of *Assistance Services of General Interest for Elderly* (ASGIE) taxonomy.

The process of categorizing the SGI tailored for elderly was an evolutionary process where the outputs of a given phase served as input for the subsequent phase in order to evolve, improve and validate the taxonomy proposed by this study. The output of the phase **"Semi-structured Interview with a Specialist"** was a first draft of the taxonomy, while the phase **"Focus Group with Experts"** provided contributions for the composition of a second draft. Afterwards, the second draft version was validated through a survey with seniors recruited in the context of the +TV4E project. Finally, after the preliminary phase of literature review and the application of three different research methods the final version of the ASGIE taxonomy was achieved (see Fig. 1). Details on the application of these several research techniques are presented below.

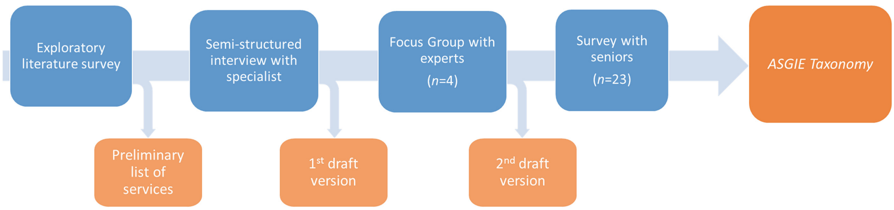

Fig. 1. Methodology towards ASGIE taxonomy [10].

3.1 Semi Structured Interview with a Specialist

Formal caregivers are the closest professionals of the elderly. Hence, in order to assess needs and sources of information of elderly with respect to SGI, it was carried out an interview with a formal caregiver. Due to times constrains, related to the schedule of +TV4E project in which this study is under development, it was only possible to carried out the interview with one formal caregiver with consolidated know-how in this field.

The selected interviewee, S.R.[1], is a gerontologist and expert in seniors' welfare promotion and active ageing in Lisbon. S.R. has 6 years of experience as formal caregiver of seniors and is a technical coordinator of a non-profit organization whose mission is to fight loneliness and isolation by providing personalized solutions. Currently, this organization provides support for 118 aged citizens living in Lisbon Downtown. An important part of her job is ensuring companionship, administering healthcare treatments, and supporting aged people with everyday activities, such as buying groceries, home cleaning and repairing (many times supported by third-party and associated services providers).

[1] The interviewee has her names hidden for ethic privacy reasons.

This interview involved questions on the following subjects: (1) the interviewee's profile (academic and professional background); (2) the organization where the interviewee works; (3) seniors' needs regarding social public services, and (4) media used by seniors to discover information about SGI. Hence, the questions below were asked:

- Which public services are the most searched by the seniors supported by your organization?
- Which are the most used ways by seniors, to access information? (e.g. flyers, internet, newspapers, TV, radio, others).
- How do seniors look for and receive information about Public Services?
- What role the formal and informal caregivers play in informing seniors about Public Service activities?
- Where do caregivers seek information? Can you help us to realize how often they look for information?

According to the interviewee, seniors usually demand information regarding general subsidies (e.g. social tariffs, housing complements and subsidies in medicines), nearby professional services (e.g. vet, house cleaning and house repairing), income taxes, retirement rules, social and civil rights, juridical support and social security. Considering the objectives of this study and of the +TV4E project, the major findings of this interview were: (a) the average digital literacy of people attended by this expert is rather low; (b) almost all seniors choose TV as the main digital medium for receiving information and for being up-to-date with general news and (c) there are many governmental and third-party Web portals currently providing public information that may be leveraged by +TV4E platform [18]. In addition, the interview provided new inputs for the services tailored for Portuguese seniors unidentified during the exploratory literature survey.

Then, the first draft version of the taxonomy was composed based on the compiled services list built during the exploratory phase as well as the contributions noted from the interview (see Fig. 1). This first draft version counted with three different domains of information: (a) Healthcare services, (b) Social services and (c) Financial services. Local (nearby) services listed during the literature research were distributed all over these three domains. In addition, some services were categorized as part of more than one domain (e.g. hospital social tariffs are both part of healthcare and financial services).

3.2 Focus Group with Experts

A focus group may be treated as a mix of participant observation and in-depth interview to characterize participants' perceptions, spontaneous opinions and attitudes [32]. It is a very useful tool for getting information about how people or a group of people think about certain topics in a session moderated by an element with experience and leadership ability.

In the context of +TV4E project, a focus group with experts in public policies development in Portugal played a key role to assess services, activities and social programs available for elderly in the country. Then, this two hours long focus group occurred in October 2016 and was formed by four research experts, three researchers of +TV4E project with expertise in designing technologies for seniors and one moderator.

Even though it is a challenging and time-consuming task, it is highly valuable to promote and learn from discussions and debates of professionals with know-how in different fields of knowledge. Concerning the peculiar inter-disciplinarity of the +TV4E project as well as the concepts covered by it, this focus group was developed with four professionals from different areas:

- a senior academic researcher on the relationship between new information and communication technologies and people/organisations;
- a researcher with background in gerontology, with research works in technology assessment for the elderly, including Ambient Assisted Living products and services, and in the field of assistive technologies use and evaluation of human functioning and environmental factors using the International Classification of Functioning, Disability and Health;
- a senior researcher and specialist in public policies planning and development; territorial governance; and economic, social and territorial impacts of Information and Communications Technologies;
- a gerontologist working in a Portuguese town hall, in the social action office, with responsibilities ranging from interventional planning to action and/or referral of problematic social situations of the elderly population.

The main purpose of this focus group was to validate the first draft of taxonomy, which was subjected to extensive review and analysis of the experts. Firstly, the participants were introduced to the main objectives of the +TV4E project. Then, the focus group was divided in four parts: (1) an initial brainstorming on the information needs of Portuguese seniors, where the participants were motivated to think about which services, resources or activities entrusted to the government they would like to receive information on TV by filling the sentence: "*If I were a senior, I would like to see on my TV the following information regarding SGI…*"; (2) validation of the service list which composed the first draft of the ASGIE taxonomy; (3) validation of the information sources, previously defined, for each of the domains of information, and (4) validation of the ASGIE concept.

Considering the objectives of the current study, the main contributions of this focus group consisted of a series of insights to reformulate the first drafted taxonomy. The experts stated that it would be necessary to come up with more than three domains of information to cover all the possible activities and social programs provided by Portuguese government authorities. Hence, the inputs gathered from these experts enabled the creation of a second draft version of the taxonomy containing seven domains of information that would be of interest of the Portuguese elderly: (a) Health Care and Welfare Services; (b) Social Services; (c) Financial Services (taxes and fees); (d) Culture, Informal education and entertainment; (e) Security services; (f) Transport services, and (g) Local authority services. These domains were formed by services, activities and social programs regulated by Portuguese authorities to benefit senior citizens. This second draft version supported the next phase and guided the survey with 23 seniors that have been already recruited to take part in the participatory design process of +TV4E project.

3.3 Survey with Seniors

Participatory design techniques are vital to research and development projects since they involve potential target users enabling a more adapted and personalized approach to improve engagement with the developed solutions. So, as a final step of the current study, involving seniors who can benefit from the +TV4E platform granted the drafted taxonomy relevance and validity.

As it is challenging to elicit valid and useful inputs from seniors in designing innovative concepts [33], a simple survey based on the second drafted taxonomy was carried out with 23 seniors. This sample was recruited in Aveiro (Portugal) and neighbouring cities. This survey occurred in November 2016, and had the list of services, activities and social programs addressed in previous phases. Thus, based on their information needs, seniors were asked to classify every item in a total of 30 items, in the list according to three levels of importance (1 = not important, 2 = important and 3 = very important). An analysis of the results achieved is presented in the Results and Discussion section.

Surveys helped to quantify interests of seniors regarding the services that comprise the taxonomy proposed by this study. The final version of the *Assistance Services of General Interest for Elderly* (ASGIE), which was the result of the preliminary literature review and the application of three research methods, is presented and discussed following.

4 A Taxonomy of Assistance Services for Seniors in Portugal

Created considering the context of SGI tailored for old citizens of Portugal, the concept of *Assistance Services of General Interest for Elderly* (ASGIE) comprehends services, activities and agreements assumed to be of essential importance to elderly citizen welfare, quality of life and social inclusion, as well as to inform about civil rights and obligation regarding public authorities. It includes all SGI related to support the elderly in Instrumental Activities of Daily Living (IADL), which are the tasks needed to enable seniors to live independently (e.g. managing finances, handling transportation and health care).

From the ASGIE concept, a taxonomy formed by seven domains was derived. These domains were organized according common interests of senior citizens regarding services, activities and social programs provided by public authorities (Fig. 2).

The taxonomy organization in domains and sub-domains, is topic-based and not necessarily "service provider"-based. In other words, this organization considers the kind of benefit obtained by the seniors and not the service provider. Therefore, each domain comprises a range of information considered to be relevant for the elderly daily activities and quality of life in a specific area. The seven domains are: Health Care and Welfare Services; Social Services; Financial Services; Cultural Services; Security Services; Transport Services and Local Authority Services.

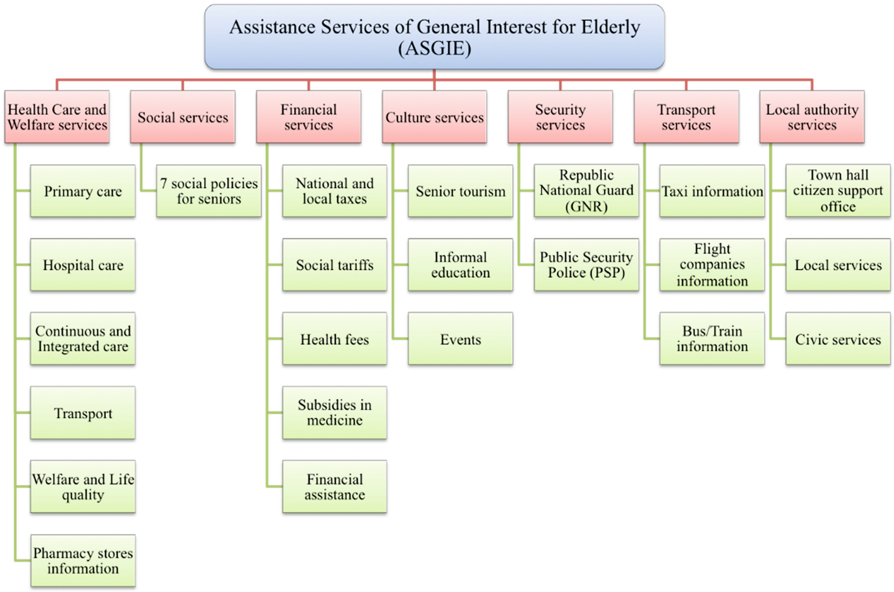

Fig. 2. The ASGIE taxonomy domains of information [10].

The **Health Care and Welfare Services** domain comprehends services, activities and social programs related to health management, divided in six areas:

- **Primary Care** – general practitioner consultation at the health centre and health promotion, such as vaccine programs and preventive methods.
- **Hospital Care** – emergency arrangements, urgency and specialized medical attendance at hospital facilities.
- **Continuous and Integrated Care** – promotion of care in an integrated manner, continuous treatment of chronic diseases, situations of dependency and loss of autonomy.
- **Transport** – emergency and continuous treatment transports.
- **Welfare and Life Quality** – healthy ageing recommendations.
- **Pharmacy Stores** – information regarding nearby pharmacies (addresses, timetables and discounts).

Concerning the **Social Services**, these play an important role in European societies by contributing to social protection and social inclusion. Considering the context of Portugal, this domain is composed by the **Seven Social Policies for Seniors:** home care services, social living centre, day care centre, night care centre, host family, nursing homes, leisure activity centres.

Portuguese authorities have several social specific measures to help lower income persons and elderly to benefit from public services. In this scenario, **Financial Services** have social programs, including lower **National and Local Taxes** (e.g. IRS[2], IRC[3], IMI[4], IUC[5]), **Social Tariffs** (discounts on water supply, telecommunications, electric, and natural gas bills, transport fares, and cultural tickets)[6], lower **Health Fees** (co-participation fees charged for using the Public Health System), **Subsidies in Medicine** and **Financial Assistance** (e.g. pensions, social security and complementary security income).

Culture Services are important for preventive health promotion as they support citizens staying active and functional for longer. These services, activities and social programs include **Senior tourism** trips; **Informal Education** courses – often provided by the Portuguese Senior Universities (www.rutis.pt); and **Events** (e.g. recreational, leisure and cultural activities).

Considering the Portuguese context of SGI tailored for old citizens, **Security Services** are composed by social programs, alerts and advices promoted by the **Republican National Guard (GNR)** and the **Public Security Police (PSP)**. Likewise, the domain of **Transport services** comprises **Taxi Information**, **Flights Information** and **Bus/Train Information**.

Finally, the **Local Authority Services** are composed by services, activities and social programs promoted by the local authority. These services are responsible for the **Town Hall Citizen Support Office** (local representative of the central power), **Local services** (exclusively services and programmes provided by the local authority), and **Civic Services** (e.g. volunteering networks).

Lastly, it is worth to mention that some services, activities and social programs may be transversal to more than one domain of information, but, for the sake of simplicity, they are mentioned in one domain only. For example, specific **Health fees** and **Subsidies in Medicine** are programs concerning the domains: **Health Care and Welfare Services**, **Social Services** and **Financial Services**. Also, **Social Tariffs** and **Financial Assistance** are programs transversal to both domains: **Social Services** and **Financial Services**.

5 Results and Discussion

The European Commission (EC) defines guidelines to foster homogeneity among the Member States, but the implementation itself of public policies is a role of every Member State. Hence, considering that it is a role of every local government to define, organize, finance and monitor their own SGI, the ASGIE concept proposed in this work

[2] Portuguese individual income tax.

[3] Portuguese corporate income tax.

[4] Portuguese municipal property tax.

[5] Portuguese motor vehicle property tax.

[6] Social Tariffs are measures launched by the Portuguese Government in order to guarantee access to the essential services taking into account socioeconomic inequalities.

is based on specific services, activities and social programs available for Portuguese elderly. Moreover, as Portugal is a Member State of the EU, some coincidences of services, activities and social programs listed in the taxonomy may be noticed in other European countries. Also, to clarify what is provided or regulated by public authorities as well as to avoid any misunderstandings on the *public* word, the ASGIE concept uses the same terminology of "general interest" created by the EC.

Though no specific studies on information needs of Portuguese seniors were found, studies conducted by researchers from other countries reveal trends of information demanded by this population segment. These studies contributed to define a first draft of the ASGIE taxonomy. In addition, as noticed during the literature survey, services, activities and social programs related to **Healthcare and Welfare Services**, **Social Services** and **Financial services** are often mentioned by seniors when it comes to their information needs. Afterwards, discussions with research specialists in welfare promotion and public policies development helped to evolve the ASGIE concept by adding four more domains: **Culture Services**, **Security Services**, **Transport Services** and **Local Authority Services**.

To check the validity of the ASGIE concept and taxonomy it was conducted a survey with seniors recruited in the context of the +TV4E project, which helped to quantify their interests regarding the services, activities and social programs that form the taxonomy. Respondents were asked to score a list of 23 items (sub-domains) using a Likert scale with 3 levels of importance (1 = unimportant, 2 = a bit important and 3 = very important). The analysis based on *Mean* and S*tandard Deviation* (SD) of the collected data is presented on Table 1. The sample addresses a total of 23 respondents, who were recruited by convenience. The female gender represented 56.5% of the sample ($n = 13$), and male 43.5% ($n = 10$). The ages ranged from 62 to 77, with an average of 69 years old. Almost all items listed in the survey were classified as important, with average of 2.1 points or more. Particularly, services, activities and social programs belonging to **Healthcare and Welfare Services**, **Social Services**, **Financial Services** and **Security Services** domains were considered very important (as depicted in Table 1). This result indicates that these domains may be considered as having essential information for daily living of seniors. The information domain considered as less important was the **Transport Services**, maybe because public transportation is not a common choice of seniors or, perhaps, because they often depend on family members and caregivers to get around. At the end of survey the respondents were able to propose additional services, activities or social programs but nobody used this field, which indicates the completeness of the taxonomy.

Categorizing information regarding SGI tailored for the Portuguese elderly is a key aspect of +TV4E project. Organizing this information according to parameters that would reflect preferences and needs of elderly is a prerequisite for a proper content selection. In this way, for example, the +TV4E iTV platform will deliver to users who are interested in the local authority roles, informative contents related to the domain of **Local Authority Services**. Thus, the content selection and matching with user preferences will be supported by the content recommender system of the +TV4E platform using the taxonomy proposed in this study [20, 21].

Table 1. Descriptive analysis of data collected in surveys with 23 seniors [10].

ASGIE domains and sub-domains of information	*Mean*	*SD*
Health care and welfare services		
Primary care	3.0	0.00
Hospital care	2.5	0.59
Continuous and integrated care	2.6	0.74
Transport	2.7	0.45
Welfare	2.6	0.50
Pharmacies	2.3	0.69
Social services		
Social support and programs	2.7	0.47
Financial services		
National and local taxes	2.6	0.50
Health fees	2.4	0.58
Subsidies in medicine	2.6	0.50
Social tariff	2.5	0.60
Financial assistance	2.6	0.58
Culture, informal education and entertainment		
Senior tourism	2.7	0.48
Entertainment	2.2	0.81
Informal education	2.1	0.83
Security services		
National republican guard	2.6	0.59
Public security police	2.6	0.59
Transport services		
Taxi number by district	2.5	0.67
Number of public transport	2.5	0.67
Airlines contact	2.1	0.71
Local authority services		
Town hall citizen support office	2.1	0.68
Specific benefits of local authorities	2.3	0.63
Civic services	1.4	0.59

6 Conclusions and Future Work

Around 40 years ago Childers and Post [34] wrote that "probably one of the most serious problems facing elderly people today is the lack of information and knowledge about existing programs and the available community resources which could meet some of their needs" [34]. Though the number of information sources available may have been increasing over the past forty years, mainly due to improvements in information and communication technologies, the current study suggests that seniors still don't access adequate information regarding services, activities and social programs they could benefit from.

This work aimed to provide a classification for SGI focused on the Portuguese elderly. Thus, this paper elaborates on a list of assistance services endowed by public authorities to old citizens and, considering the Portuguese context, proposes the concept and taxonomy of *Assistance Services of General Interest to the Elderly* (ASGIE).

To fundament and validate the ASGIE concept and the taxonomy, research experts in welfare promotion and public policies development were called to participate in an interview and a focus group. Contributions from these specialists served as guidelines to a survey conducted with 23 seniors. This survey allowed the validation of the relevance of the domains and sub-domains structuring ASGIE taxonomy.

In addition, as a future research study it is necessary to assess acceptable data sources regarding the ASGIE domains to retrieve information from. Though some contributions in this regard were noted during the interview and the focus group with specialists, a detailed study should be performed in a near future to gather adequate information about this topic. This is a very important subject as these sources will be used as feeds for the +TV4E platform to automatically generate video informative contents.

The reduced size of the sample of the survey may limit the significance of achieved results. Although it should not be overlooked that the findings show homogeneity and agreement, both across literature and the participants of this study, which gives consistency to the results that supported the proposed taxonomy. Thus, as future steps, the research team intends to extend the survey application, so that the results can be representative of the Portuguese population.

Findings from this research will be very valuable for the +TV4E project in its upcoming development stages towards a personalized system for the elderly, enhancing the probabilities of adherence and acceptance by its target users. An appropriate categorization of the informative contents handled by the iTV platform guarantees a proper implementation of the +TV4E recommendation system [21].

Finally, in order to accomplish the Europe 2020 guidelines for development of innovative Services of General Interest [9], Portuguese authorities in charge of designing, implementing and monitoring public policies for seniors can use these findings as indicators of information needs of this population segment. Furthermore, studies like this can be an asset to other countries to evaluate information needs of their senior citizens. Fulfilling seniors' information needs is essential to promote their health and quality of life.

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Correction to: What Is Hip? – Classifying Adopters and Rejecters of Interactive Digital Textiles in Home Environments

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